VITAL SIGNS MONITORING PLAN

Phase II Report

Northeast Temperate Network

October 2004

EXECUTIVE SUMMARY

The National Park Service (NPS) initiated a new "Vital Signs" program in 1998 to develop comprehensive, long-term monitoring of ecological resources within U.S. national parks. Vital signs are indicators, and are defined as are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. This report documents the progress of the Northeastern Temperate Network in implementing the first two Phases of this program. In Phase 1, baseline inventories and analysis of threats provided information to build conceptual ecological models for four ecosystem groups – terrestrial, wetland, aquatic, and intertidal systems. In Phase 2, the core science team developed a list of more than 100 potential vital signs. This preliminary list was peer-reviewed to develop a final list of 23 high priority vital signs, with 104 associated potential measures. In Phase 3, protocols will be developed for groups of vital signs. To ensure that the final set of measured vital signs produce reliable inference within cost constraints of NETN, statistical power analyses and cost assessments will be an integral part of Phase 3. Because timely reporting and communication is a primary component of a successful monitoring program, we will incorporate standard summaries of statistical trends in vital signs measures after each implementation period. We will also develop a rating scheme to allow integration of vital signs into an overall ecological integrity rank for particular occurrences of an ecosystem. The ranks can be used as part of an "Ecological Integrity Scorecard" that provides an important communication tool for adaptive management, which requires that information be communicated in a way that informs management decisions and can be understood by a diverse audience.

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Greg Shriver is the Network Coordinator and Fred Dieffenbach is the biologist / data manager for the NETN. They, along with Don Faber-Langendoen, Geraldine Tierney, Pam Lombard, and James Gibbs form the core science team for the Phase II report. John Gunn is developing information on the Appalachian Trail. Ben Rubin and Shawn Carter assisted the team during earlier work on the Phase I report.

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Chapter 1 Introduction and Background

1.1 The NPS Vital Signs Program and the Northeast Temperate Network

Recognizing the need for comprehensive, long-term monitoring of ecological resources within the U.S. National Park System, the National Park Service (NPS) undertook a major new initiative in 1998 to develop a program for long-term monitoring of "Vital Signs," or indicators, of ecological integrity within the parks. Vital signs are a subset of physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. This Inventory & Monitoring (I&M) program is being implemented within 270 parks, which have been grouped into 32 park networks, using a consistent framework and process.

The Northeast Temperate Network (NETN) consists of 10 parks in 7 states, plus the Appalachian Trail, which traverses the NETN region from Maine to Pennsylvania. The Appalachian Trail (APPA) is coordinating inventory and monitoring activities throughout its length (from Maine to Georgia) with the NETN, thus NETN will coordinate monitoring efforts with the four other networks that intersect with the APPA. The 11 "parks" within the NETN are grouped together based on their common ecological resources - northeastern temperate forests and the wetland and aquatic systems that accompany them.

As with other NPS networks, NETN seeks to identify and define appropriate vital signs of ecological integrity and to establish protocols for their measurement. NETN has focused on identifying indicators representing the diversity of ecological systems and anthropogenic stressors within parks at a range of ecological scales. The challenge is to identify a coherent set of indicators that cover the range of ecological resources and stressors found in the network, within the budgetary constraints of the program, and which can be meaningfully compared to indicators selected by other NPS networks and other monitoring programs. The NETN vital signs program must also provide effective communication tools that allow park managers and other audiences to interpret meaningful changes to park ecological integrity; in order to do so, NETN plans to employ an innovative ecological integrity ranking scheme described herein.

The overall process for developing the NPS vital signs program has been outlined by the NPS Vital Signs Program (http://science.nature.nps.gov/im/monitor/index.htm; see also Fancy 2004, Gross 2004). Briefly, the I&M Vital Signs Program incorporates a three-phase approach:

Phase 1 - define goals and objectives; begin the process of identifying, evaluating and synthesizing existing data; develop draft conceptual models; and complete other background work;

Phase 2 - prioritize and select vital signs and develop specific monitoring objectives for each park and the network; and, *Phase 3* - develop detailed plans to implement monitoring, including the development of sampling protocols, a statistical sampling design, a plan for data management and analysis, and expectations for reports and other presentation of results.

Herein we present here our progress on Phases I and II of this program.

1.2 Purpose

1.2.1 Justification for Integrated Natural Resource Monitoring

Knowing the condition of natural resources within national parks is fundamental to NPS's ability to manage park resources "unimpaired for the enjoyment of future generations." National Park managers are confronted with increasingly complex and challenging issues that require a broad-based understanding of the status and trends of park resources. For years, managers and scientists have sought a way to characterize and determine trends in the condition of parks and other protected areas in order to assess the efficacy of management practices and restoration efforts, and to provide early warning of impending threats. The challenge of protecting and managing a park's natural resources requires a multi-agency, ecosystem approach because most parks are open systems, with many threats, such as air and water pollution and invasive species, originating outside of park boundaries. Moreover, an ecosystem approach is needed because no single spatial or temporal scale is appropriate for all system components and processes. The appropriate scale for understanding and effectively managing a resource might range spatially from site-specific to regional, and might vary temporally from sub-annual to decadal or more. In some cases a regional, national or international effort may be required to understand and manage the resource. National parks are part of larger ecosystems and must be managed in that context.

Natural resource monitoring provides site-specific information needed to identify and understand changes in complex, variable, and imperfectly understood natural systems and to provide insight into whether observed changes are within natural levels of variability or indicate undesirable human influence. Thus, monitoring provides a basis for identifying and understanding *meaningful change* in natural systems characterized by complexity, variability, and non-linear responses. Monitoring results can be used to identify threatened or impaired resources and initiate or change management practices. Understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making designed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Roman and Barrett 1999).

The intent of the NPS monitoring program is to track a subset of park resources and processes, representing significant indicators of ecological condition; these indicators are called "vital signs." These indicators must be a useful subset of the total suite of natural resources that park managers are directed to preserve "unimpaired for future generations," including water, air, geological resources, plants and animals, and the various ecological, biological, and physical processes that act on these resources. By choosing a meaningful subset of ecological resources, NPS recognizes that tracking everything is neither possible nor desirable. In situations where natural areas have been so highly altered that physical and biological processes no longer operate (e.g., control of fires or floods in developed areas), information obtained through monitoring can help managers understand how to develop the most effective approach to restoration or, in cases where restoration is impossible, ecologically sound management. The broad-based, scientifically sound information obtained through natural resource monitoring will have multiple applications for management decision-making, research, education, and promoting public understanding of park resources.

1.2.2 Legislation, Policy and Guidance

National Park managers are directed by federal law and National Park Service policies and guidance to know the status and trends in the condition of natural resources under their stewardship in order to fulfill the NPS mission of conserving parks unimpaired. The mission of the National Park Service (National Park Service Organic Act, 1916) is:

"...to promote and regulate the use of the Federal areas known as national parks, monuments, and reservations hereinafter specified by such means and measures as conform to the fundamental purposes of the said parks, monuments, and reservations, which purpose is to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations".

Congress strengthened the National Park Service's protective function, and provided language important to recent decisions about resource impairment, when it amended the Organic Act in 1978 to state that *"the protection, management, and administration of these areas shall be conducted in light of the high public value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established…".*

More recently, the National Parks Omnibus Management Act of 1998 established the framework for fully integrating natural resource monitoring and other science activities into the management processes of the National Park System. The Act charges the Secretary of the Interior to "*continually improve the ability of the National Park Service to provide state-of-the-art management, protection, and interpretation of and research on the resources of the National Park System*", and to *"… assure the full and proper utilization of the results of scientific studies for park management decisions*." Section 5934 of the Act requires the Secretary of the Interior to develop a program of "*inventory and monitoring of National Park System resources to establish baseline information and to provide information on the long-term trends in the condition of National Park System resources*."

Congress reinforced the message of the National Parks Omnibus Management Act of 1998 in its text of the FY 2000 Appropriations bill:

"The Committee applauds the Service for recognizing that the preservation of the diverse natural elements and the great scenic beauty of America's national parks and other units should be as high a priority in the Service as providing visitor services. A major part of protecting those resources is knowing what they are, where they are, how they interact with their environment and what condition they are in. This involves a serious commitment from the leadership of the National Park Service to insist that the superintendents carry out a systematic, consistent, professional inventory and monitoring program, along with other scientific activities, that is regularly updated to ensure that the Service makes sound resource decisions based on sound scientific data."

The 2001 NPS Management Policies updated previous policy and specifically directed the Service to inventory and monitor natural systems:

"Natural systems in the national park system, and the human influences upon them, will be monitored to detect change. The Service will use the results of monitoring and research to understand the detected change and to develop appropriate management actions".

Further, "The Service will:

- Identify, acquire, and interpret needed inventory, monitoring, and research, including applicable traditional knowledge, to obtain information and data that will help park managers accomplish park management objectives provided for in law and planning documents;
- Define, assemble, and synthesize comprehensive baseline inventory data describing the natural resources under its stewardship, and identify the processes that influence those resources;
- Use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals;
- Analyze the resulting information to detect or predict changes, including interrelationships with visitor carrying capacities, that may require management intervention, and to provide reference points for comparison with other environments and time frames;
- Use the resulting information to maintain-and, where necessary, restore-the integrity of natural systems" (2001 NPS Management Policies).

Box 1:
Statutes that provide legal direction for expending funds to determine the condition of natural resources in parks and specifically guide the natural resource management of network parks:

- Taylor Grazing Act 1934;
- Fish and Wildlife Coordination Acts, 1958 and 1980;
- Wilderness Act 1964;
- National Historic Preservation Act 1966;
- National Environmental Policy Act of 1969;
- Clean Water Act 1972, amended 1977, 1987;
- Endangered Species Act 1973, amended 1982;
- Migratory Bird Treaty Act, 1974;
- Forest and Rangeland Renewable Resources Planning Acts of 1974 and 1976;
- Mining in the Parks Act 1976;
- American Indian Religious Freedom Act 1978;
- Archaeological Resources Protection Act 1979;
- Federal Cave Resources Protection Act 1988

These are among the many additional statutes that provide legal direction for expending funds to determine the condition of natural resources in parks and specifically guide the natural resource management of network parks (See Box 1).

1.3 Monitoring Goals and Strategies

1.3.1 Role of Monitoring

Monitoring is a central component of natural resource stewardship in the National Park Service, and in conjunction with natural resource inventories and research, provides the information needed for effective, science-based managerial decision-making and resource protection (Figure 1.1). The NPS strategy to institutionalize inventory and monitoring throughout the agency is based on a framework that consists of several key components; (a) completion of 12 basic resource inventories upon which monitoring efforts can be based, (http://science.nature.nps.gov/im/inventories.htm) (b) a network of 11 experimental or "prototype" long-term ecological monitoring programs initiated in 1992 to evaluate alternative monitoring designs and strategies, and (c) implementation of operational monitoring of critical parameters (i.e. "vital signs") in 270 parks with significant natural resources that have been grouped into 32 networks linked by geography and shared natural resource characteristics. NETN is one of these 32 networks.

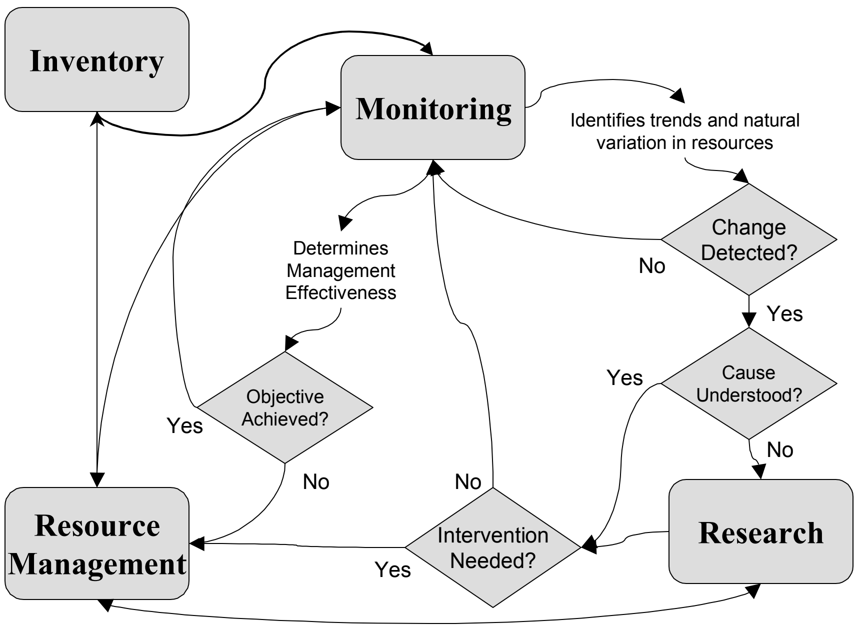


__Figure 1.1.__ Relationships between monitoring, inventories, research, and natural resource management activities in national parks.

1.3.2 Service-wide Vital Signs Monitoring Goals

Servicewide Goals for Vital Signs Monitoring for the National Park Service are as follows:

- Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better-informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources;
- Provide early warning of abnormal conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management;
- Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other, altered environments;
- Provide data to meet certain legal and Congressional mandates related to natural resource protection and visitor enjoyment;
- Provide a means of measuring progress towards performance goals.

These general goals will be supplemented by specific goals for the Northeast Temperate Network (see section 1.6 below), after the basic park natural and cultural resources and management issues have been presented.

1.3.3 The Three-Phase Process for the I&M Monitoring Program

During the initial planning for park vital signs monitoring, it became clear that a "one size fits all" approach to monitoring would not be effective within NPS due to the tremendous variability among parks in ecological conditions, sizes, and management capabilities. To develop an effective and cost-efficient monitoring program that addresses the information needs of each park and integrates across other park operations like interpretation and maintenance, parks need the flexibility to allow existing programs, funding,and staff to be combined with new I & M program. Partnerships with federal and state agencies and adjacent landowners are necessary to effectively understand and manage resources and threats that extend beyond park boundaries, and these partnerships will vary across the national park system. For example, parks in the Pacific Northwest will need to select indicators and methodologies that are consistent with the Northwest Forest Plan, whereas parks in South Florida, in conjuction with the U.S. Army Corps of Engineers, South Florida Water Management District, and other partners, may select a completely different set of indicators and sampling protocols appropriate to restoration of the everglades ecosystem.

The complicated task of developing a network monitoring program requires an initial investment in planning and design to guarantee that monitoring meets the most critical information needs of each park, and produces scientifically credible results that are clearly understood and accepted by scientists, policy makers, and the public, and that are readily accessible to managers and researchers. These front-end investments also ensure that monitoring will build upon existing information and understanding of park ecosystems and make maximum use of leveraging and partnerships with other agencies and academia.

The NPS has established a 3-phase planning and design process for the I & M program. *Phase 1* involves defining network goals and objectives; identifying and synthesizing existing data; developing conceptual ecological models of park resources; and completing other background work. *Phase 2* involves prioritizing and selecting vital signs using a process of scientific peer review. *Phase 3* involves the development of specific sampling protocols, a statistical sampling design, a plan for data management and analysis, and a plan for reporting monitoring results. After completion of each Phase, each network reports their progress for NPS review within a structured report (such as this report). The timeline for accomplishing these phases within NETN is presented in Table 1.1.

We used a standard process to begin Phase 1 of the development of long-term ecological monitoring within NETN (Figure 1.2). We began with a series of brainstorming sessions, questionnaires, meetings and scoping workshops (Table 1.2) to identify: (1) focal resources and ecological processes important within NETN parks, (2) key stressors or agents of change known or suspected to be acting upon NETN ecological resources; and (3) key elements and processes representing ecological integrity within these ecological resources. Conceptual models were then developed to help organize and communicate this information, and identify cause and effect relationships between stressors and response variables (see Chapter 2).

Table 1.1. *Timeline for the Northeast Temperate Network to complete the 3-phase planning and design process for developing a monitoring program.*

ACTIVITY	FY01 Oct-Mar	FY01 Apr-Sep	FY02 Oct-Mar	FY02 Apr-Sep	FY03 Oct-Mar	FY03 Apr-Sep	FY04 Oct-Mar	FY04 Apr-Sep	FY05 Oct-Mar	FY05 Apr-Sep
Data gathering,										
Inventories to										
Scoping										
Conceptual										
Indicator										
Protocol										
Monitoring Plan Due Dates Phase 1, 2, 3						Phase 1 Oct. 03		Phase 2 Oct. 04		Phase 3 Dec. 05

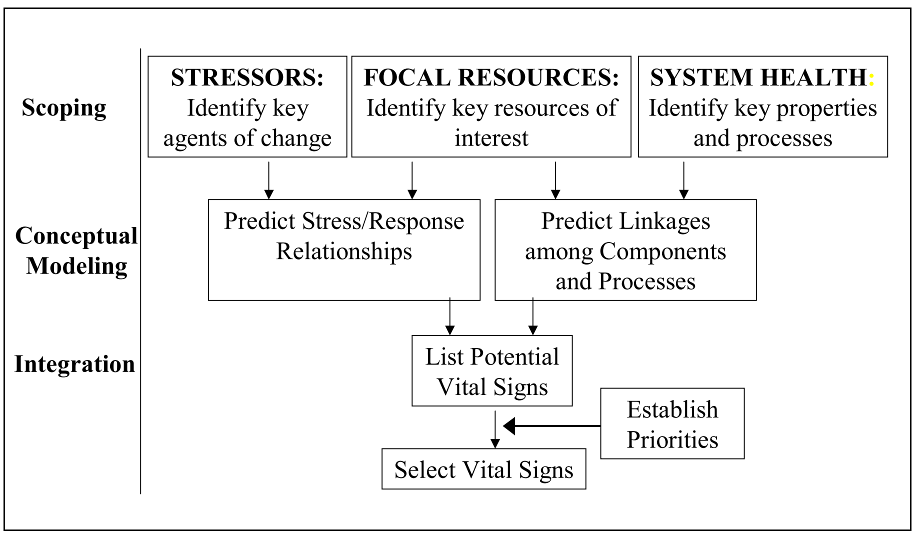


Figure 1.2. *The basic approach to identifying and selecting vital signs for integrated monitoring of park resources (source: Kurt Jenkins, USGS Olympic Field Station).*

Table 1.2. Workshops/meetings held to implement the monitoring program in the Northeast Temperate Network, 2000-2004.		
PHASE	MILESTONES	DATES
Phase 1	Assessing Natural Resources	
	Identify Priorities for Inventory Needs	May 2001- Dec. 2003
	Identify Significant Resources, Prioritize Management Issues, Identify Monitoring Needs for each park.	August 2003
	Developing Program Resources	
	First NETN Board meeting to review program and charter	December 2002
	Create Core Science Team	December 2002
	Park-based scoping meetings	January – May 2003
	Phase I Plan	
	Phase I draft review – Acadia NP (conceptual models)	October 2003
	Complete Phase I Report	October 2003
Phase II	Phase II Plan	
	Technical Committee Planning Meeting	November 2003
	Vital Signs Selection Workshop	May 2004
	Technical Committee / Parks Review Workshop	August 2004
	Submit Phase II Report	October 2004
Phase III	(to be developed)	

1.3.4 An Integrated Approach to Monitoring

A key initial decision in designing a monitoring program is balancing the need to monitor for current management issues against the need to detect future, perhaps unforeseen threats to park ecosystems. Many have enumerated advantages and disadvantages of these two approaches (Woodley 1993, Noon 2002). Our ability to predict ecosystem response to changes in various system drivers and stressors is limited by our incomplete understanding of ecological systems and processes. A monitoring program that only focuses on well-known threat/response relationships will not provide the long-term information and understanding necessary to address unanticipated, high-priority issues that will arise in the future.

Alternatively, monitoring key ecological properties and processes indicative of ecosystem integrity will allow detection of change in response to unforeseen or uncharacterized stressors and perhaps provide early warning of unacceptable change. Ecological integrity can be defined as “the maintenance of ... structure, species composition, and the rate of ecological processes and functions within the bounds of normal disturbance regimes” (Lindenmayer and Franklin 2002). This concept builds on earlier definitions of biological integrity, defined as the capacity to support and maintain a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats of the region (Karr et al. 1986); ecological integrity is a broader concept which incorporates aspects of abiotic condition such as air or water quality.

NETN seeks to combine these two complementary approaches, by selecting a suite of indicators that measure both known stressors and ecological integrity (Figure 1.3). This approach is consistent with that advocated by the I&M program, which stresses that Vital Signs include: 1) physical, chemical, and biological elements and processes of park ecosystems that are selected to represent the overall health or condition of park resources; 2) known or hypothesized effects of stressors; and 3) or elements that have important human values.

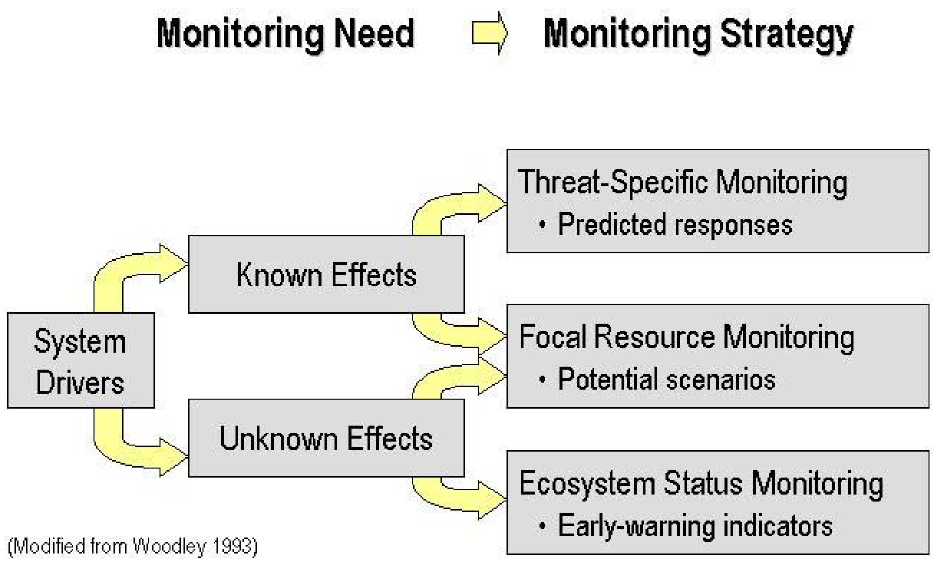


Figure 1.3. *Conceptual approach for selecting monitoring indicators.*

Moreover, an integrated monitoring program should yield information at multiple spatial and temporal scales, across major disciplines, and that is useful across program boundaries. NETN seeks to develop a program that incorporates the following aspects of integration:

Ecological Integration involves considering the ecological linkages among system drivers and the components, structures, and functions of ecosystems when selecting monitoring indicators. An effective ecosystem monitoring strategy will employ a suite of individual measurements that collectively monitor the integrity of the entire ecosystem. One approach for effective ecological integration is to select indicators at various hierarchical levels of ecological organization (e.g., landscape, community, population, genetic; see (Noss 1990).

Spatial Integration involves establishing linkages of measurements made at different spatial scales. It requires understanding of scalar ecological processes, the collocation of measurements of comparably scaled monitoring indicators, and the design of statistical sampling frameworks that permit the extrapolation and interpolation of scalar data.

Temporal Integration involves establishing linkages between measurements made at various temporal scales. It will be necessary to determine a meaningful timeline for sampling different indicators while considering characteristics of temporal variation in these indicators. For example, sampling changes in the structure of a forest overstory (e.g., size class distribution) may require much less frequent sampling than that required to detect changes in the composition or density of herbaceous groundcover. Temporal integration requires nesting the more frequent and, often, more intensive sampling within the context of less frequent sampling.

Programmatic Integration involves the coordination and communication of monitoring activities within and among parks, among divisions of the NPS Natural Resource Program Center, and among the NPS and other agencies, to promote broad participation in monitoring and use of the resulting information. At the park or network level, involving a park's law enforcement, maintenance, and interpretative staff in monitoring activities and reporting results in a clear, concise format, creates a well-informed park staff, improved potential for informing the public, greater acceptance of monitoring results in the decision-making process, and therefore, wider support for vital signs monitoring. The systems approach to monitoring planning and design requires a coordinated effort by the NRPC divisions of Air Resources, Biological Resource Management, Geologic Resources, Natural Resource Information, and Water Resources to provide guidance, technical support and funding to the networks. Finally, there is a need for the NPS to coordinate monitoring planning, design and implementation with other agencies to promote sharing of data among neighboring land management agencies, while also providing context for interpreting the data.

1.3.5 Interpreting Ecological Integrity

Ultimately, a vital sign is useful only if it provides information useful in guiding management decisions or quantifying the success of past decisions. This information must be presented in a way that is clearly understood by managers, scientists, policy makers, and the public. NETN plans to accomplish this task by 1) developing standard statistical summaries of vital sign measurements, and 2) developing an ecological integrity scorecard that provides basic interpretation of trends.

First, our protocols will clearly specify standard statistical methods for detection of trends for all vital signs. These will include aggregate trends among related vital signs and aggregate trends among vital signs within particular ecosystem types. We hope to co-locate ("bundle") measurements of many vital signs at standard locations, and correlations among them will also permit general inferences about particular regions. By progressing in this manner, we will determine meaningful effect sizes for each vital sign measure (as these dramatically affect sample size and overall cost), and thereby, track the accrual of monitoring costs to make cost-effective decisions about which vital sign measures can be included in the initial phase of program implementation.

Second, NETN plans to develop an ecological integrity scorecard into the reporting process for the NETN Vital Signs Program. Powerful communication tools are necessary to transform a collection of field data into a format that shows managers whether and how ecological integrity is changing. Communicating trends in twenty or more vital signs and the multitude of associated measures will require a framework that clearly and concisely conveys the state of the park ecosystems. The developing of an ecological integrity scorecard during Phase 3 will provide the NETN with the necessary framework to effectively communicate this information. Ultimately this scorecard will be an aggregated matrix, in which individual measures are rated and compiled into an overall assessment of the integrity of an ecological system (Harwell et al. 1999, NatureServe 2002, Young and Sanzone 2002, Parrish et al. 2003). It may take the form of a series of ecological integrity indices, ranks or scorecards (Appendix A).

1.3.6 Limitations of Monitoring

Managers and scientists must acknowledge limitations of monitoring that result from the inherent complexity and variability of park ecosystems, as well as those resulting from the limitations of resources available for monitoring. Ecosystems are loosely defined assemblages that exhibit characteristic patterns on a range of scales of time, space, and organizational complexity (De Leo and Levin 1997). Definitions of ecological integrity are problematic, partly because key terms such as "natural" remain vague (Noon 2002). Natural systems as well as human activities change over time, and it is extremely challenging to separate natural variability and desirable changes from undesirable anthropogenic sources of change to park resources. Moreover, limiting funding prevents us from directly monitoring all resources that might be at risk. These complexities demand that we recognize our limited understanding of ecological systems and processes, especially as we attempt to use this information to inform management decisions.

In some cases, monitoring data might suggest a cause and effect relationship that can then be investigated by a research study. As monitoring proceeds, as data sets are interpreted, as our understanding of ecological processes is enhanced, and as trends are detected, future issues will emerge (Roman and Barrett 1999). The monitoring plan should therefore be viewed as a working document, subject to periodic review and adjustments over time as our understanding improves and new issues and technological advances arise.

1.4 Ecological Resources of the Northeast Temperate Network

1.4.1 Overview of Parks and Ecological Resources

The NETN contains 11 parks (Table 1.3), including a section of the Appalachian NST. These parks contain diverse cultural and natural resources within eight states (ME, NH, VT, MA, CT, NY, NJ, and PA) and span two ecological divisions (Laurentian / Acadian and Central Interior & Appalachian, Figure 1.4). Parks within the Network range geographically from Acadia NP in coastal Maine to Morristown NHP in central New Jersey.

NETN parks range in size from ≈ 9 acres at Saugus Iron Works to ≈ 85,000 acres covered by the Appalachian Trail (NPS lands from ME-MD), include the beginning and end of the Revolutionary War (Minute Man NHP and Saratoga NHP respectively), and a strategic military location for General George Washington (Morristown NHP). Two National Historic Parks commemorate the lives of artists (Saint-Gaudens NHS and Weir Farm NHS) and Roosevelt-Vanderbilt NHS celebrates the lives of the "Gilded Age". Marsh-Billings-Rockefeller NHP and Boston Harbor Islands NPA are both new to the NPS and unique in their establishment and mandates. Marsh-Billings-Rockefeller NHP is the only national park to focus on conservation history and the evolving nature of land stewardship. Boston Harbor Islands, established in 1996, are a culturally and naturally diverse set of 34 drowned drumlins in the Massachusetts Bay managed by a 13-member partnership. Saugus Iron Works NHS marks the site of the first integrated iron works in North America, which gave rise to the industrial revolution and is known as the forerunner of America's industrial giants. Acadia is the only National Park in the NETN and hosts a diverse array of cultural, natural, and geologic resources. The Appalachian

Trail, crosses some of the most diverse ecological communities in the Northeast, is managed by a unique partnership with the NPS and the Appalachian Trail Conference, and provides an exciting opportunity for ecological monitoring across 2,100 miles of habitat representative of the entire east coast of the US. Fuller details on each of the parks are provided in Appendix B. Eight of the eleven NETN parks are National Historic Parks or Sites, and thus have a primary mandate to maintain historical features, landscapes or practices. This special mandate has a substantial impact on ecological resources within these parks, as they are often managed to maintain early successional habitats, or incorporate agriculture or forestry within the parks to satisfy this mandate.

All the parks in the Network are located within the temperate deciduous forest biome. Temperate deciduous forests are located in mid-latitude areas between the Polar Regions and the tropics and are exposed to both warm and cold air masses that cause this region to have four distinct seasons. Temperature varies widely from season to season, with long, cold winters and warm summers. Within NETN, the average annual temperature ranges from about 11˚ C along the southern coast to 4˚ C in the northern highlands. Annual precipitation ranges from 90-120 cm and is relatively evenly distributed throughout the year.

Table 1.3. *Summary of parks in the Northeast Temperate Network.*

Park Name	Code	Size (acres)	% Total Area	Annual Visits	% Total Visits
Acadia NP (ME)	ACA	47,498	0.34	2,504,708	52
Appalachian NST (ME-PA)	APPA	85,036	0.60	NA	NA
Boston Harbor Islands NPA	BOH	1,465	0.01	NA	NA
Marsh-Billings-Rockefeller NHP	MAB	643	<0.01	28,699	<1
Minute Man NHP (MA)	MIM	967	0.01	1,064,389	22
Morristown NHP (NJ)	MOR	1,707	0.01	422,758	9
Roosevelt-Vanderbilt NHS (NY)	ROV	778	<0.01	594,884	12
Saint-Gaudens NHS (NH)	SAG	150	<0.01	47,801	<1
Saratoga NHP (NY)	SAR	3,392	0.02	152,854	3
Saugus Iron Works NHS (MA)	SAIR	9	<0.01	17,050	<1
Weir Farm NHS (CT)	WEF	74	<0.01	16,820	<1

Temperate deciduous forests are dominated by broadleaf trees, including oak, hickory, maple, beech, and birch, often mixed with conifers such as hemlock, spruce, fir, and pine on drier or higher elevation sites. Network forests range from the drier central hardwoods oak-pine or oak-hickory stands through mesic northern hardwoods to spruce-hardwoods. Other terrestrial habitats include alpine vegetation, rocky outcrop woodlands and both old-field successional habitats and plantations. A variety of wetland and aquatic habitats are present within these forests, including forested and shrub swamps, marshes, wet meadows, fens and bogs, lakes, rivers, ponds and vernal pools. In addition, intertidal habitats are present at Acadia and Boston Harbor Islands.

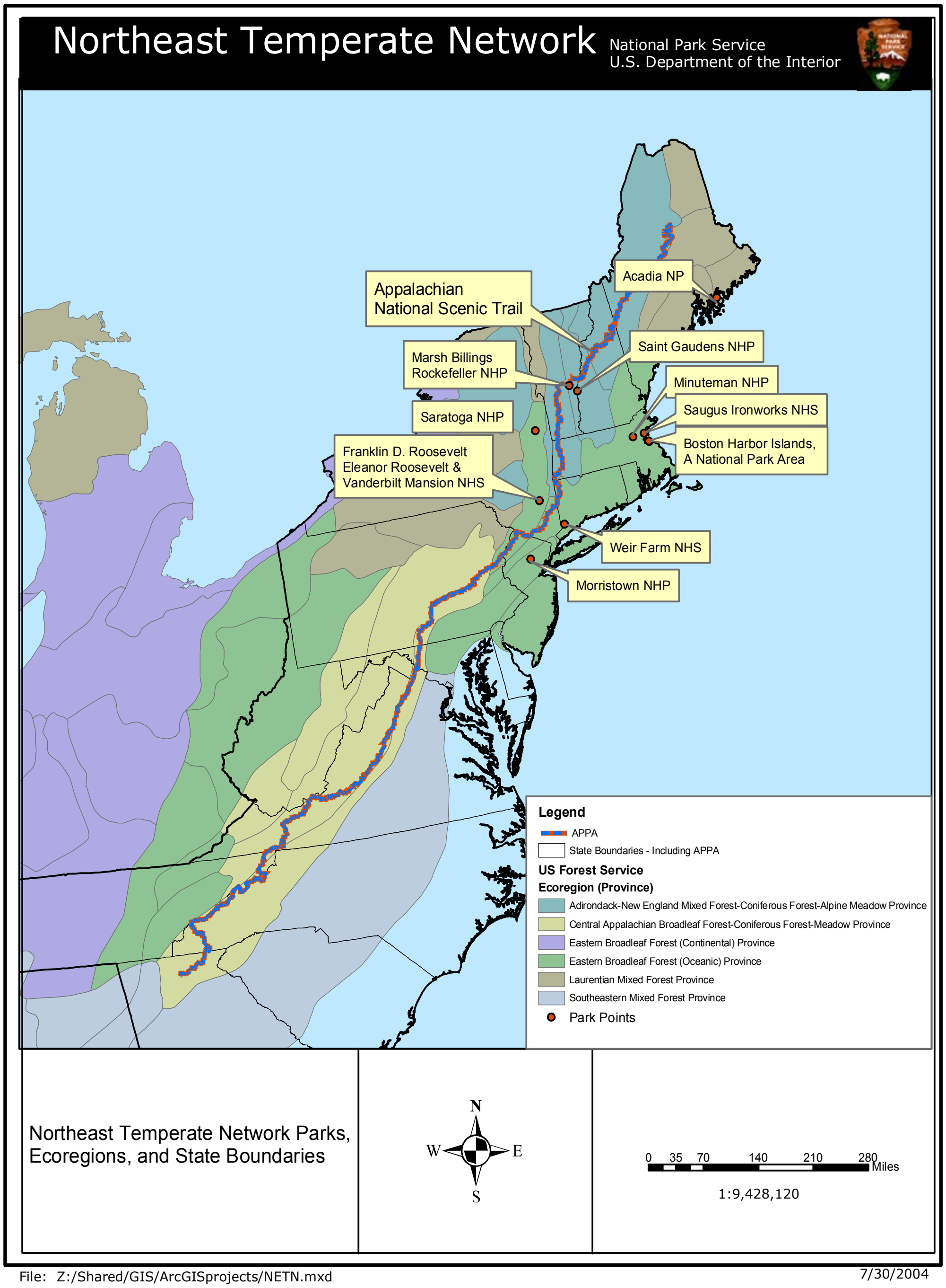


Figure 1.4. *Location of NETN parks with respect to the ecoregions of the eastern US.*

Worldwide, temperate deciduous forests have been highly altered, having the highest index of human disturbance of any major biome (Hannah et al. 1995), and having high indices of fragmentation (Ritters et al. 2000). The northeast is no exception. Temperate deciduous forests in the northeast have been heavily utilized for timber, cleared for agriculture, or converted into towns and cities. Even so, regrowth of forests on abandoned farms in the last 50-100 years has created a new mix of primary and secondary forests, and increased levels of overall forest cover (Foster and Aber 2004).

1.4.2 Ecological Systems and Communities

An effective monitoring program requires accurate assessments of the patterns of ecological systems. Systems in each park are being mapped using the U.S. Geological Survey - National Park Service (USGS - NPS) Vegetation Mapping Program (http://biology.usgs.gov/npsveg/), which is one of the inventories specified by the Natural Resource Challenge. The vegetation mapping program is mapping a large percentage of the NPS land base using two complementary classification schemes 1) the U.S. National Vegetation Classification (USNVC), a federal standard for classification of terrestrial ecological communities based on vegetation; and 2) NatureServe's Ecological Systems classification (Comer et al. 2003, NatureServe 2003b), a broader classification tool. Many government agencies and other organizations use the USNVC, thus this classification scheme allows comparison of park data with that of other groups. Currently, system and vegetation maps are completed or underway for all Network parks (Table 1.4, and see Appendix B). This mapping and classification effort will also allow NETN to determine the global, state and local conservation status, or relative rarity, of park ecological systems.

Table 1.4. *Expected completion dates for USGS Vegetation Mapping Program project for NETN parks.*

Park Name	Expected completion date for
Acadia NP (ME)	completed
Appalachian NST	scoping
Boston Harbor Islands NPA (MA)	scoping
Marsh-Billings-Rockefeller NHP (VT)	2005
Minute Man NHP (MA)	2005
Morristown NHP (NJ)	2005
Roosevelt-Vanderbilt NHS (NY)	2005
Saint-Gaudens NHS (NH)	2005
Saratoga NHP (NY)	2005
Saugus Iron Works NHS (MA)	2005
Weir Farm NHS (CT)	2005

While these mapping efforts are in progress, information has been compiled from draft maps and other park sources to approximate the extent of major ecological system groups within each park (Table 1.5; see also Appendix C). To address larger issues of historic patterns of land-cover change, the Network has undertaken a project to map present land cover and estimate land cover change since the early 1970s around each NETN park, including part of the Appalachian Trail. This information will provide the landscape context for all NETN parks.

NETN is comprised of a diverse array of ecological systems including terrestrial systems, wetland systems, intertidal systems, and a variety of lakes and streams (Table 1.5). National historic parks and sites also include a variety of human-modified systems that are maintained as part of the parks' cultural mandate. Parks vary widely in the amount of land area represented by each system group. Terrestrial systems dominate all NETN parks except Boston Harbor and Saugus Iron Works, in which intertidal or wetland systems are dominant. Acadia contains extensive systems in all categories. Minute Man also has extensive wetlands. Important aquatic systems are present at Saint-Gaudens and Saratoga as well as Acadia.

Park size and cultural mandate must both be considered in addition to ecological systems in the design of Vital Sign Monitoring within these parks. All the parks but Acadia and the Appalachian Trail are small, meaning that outside landscape and regional factors have strong influences. The historic parks and sites contain relatively fewer natural ecological systems, but the maintained early-successional habitat within those parks may have other important ecological value, such as providing habitat for grassland birds.

Table 1.5. *Area (hectares) of general system groups within each park.*

PARK	Terrestrial	Wetland	Intertidal	Aquatic
ACAD	13,215	904	118	980
APPA	N/A	N/A	N/A	N/A
BOHA	143	20	420	<1
MABI	218	4	0	6
MIMA	250	105	0	1
MORR	490	15	0	<1
ROVA	251	12	0	6
SAGA	51	5	0	2
SAIR	1	2	0	<1
SARA	1082	37	0	2
WEFA	27	4	0	2

1.4.3 Biodiversity Assessments

A variety of surveys have assessed the species and community diversity of NETN parks. These include surveys of local populations of state or globally ranked rare species, or federally listed species, as well as exemplary occurrences of natural communities. Heritage programs have historically visited parks within the Network to identify these rare communities and species (Appendix D). Over 514 species and 863 occurrences are documented within NETN parks (Table 1.6), the majority found on the Appalachian Trail. Many of these occurrences have been assigned a population viability or ecological integrity rank, based on the qualitative NatureServe/Heritage Network ranking methodology (NatureServe 2002). The ecological integrity ranks will be reassessed as part of this Vital Signs monitoring program, and will serve as a baseline measure of ecological condition. Integration of these ranks into the program will be developed during Phase 3.

1.4.4 Management Issues for Network Parks – Assessing Threats

Scientific and management issues relevant to natural resource stewardship in the 11 NETN parks were synthesized in scoping workshops and questionnaires. Land use change surrounding parks,

Table 1.6. *The number of tracked species and communities found in each park, and the number of occurrences, based on Natural Heritage Program databases. Tracked species and communities include those that are both state and globally rare. (S1-S3, G1-G3. * All communities in each park are being mapped by the USGS Vegetation Mapping Program and additional occurrences may be documented. APPA includes records from Maine to Georgia.*

Park	Plants and Animals	Total No. of Occurrences	Communities*	Total No. of Occurrences
ACAD	15	33	13	15
APPA	485	817	65	122
BOHA	N/A	N/A	6	10
MABI	2	?	N/A	N/A
MIMA	N/A	N/A	2	3
MORR	0	0	0	0
ROVA	4	5	2	2
SAGA	6	6	1	1
SAIR	0	0	0	0
SARA	2	2	N/A	N/A
WEFA	0	0	0	0
Total	514	863	89	153

habitat fragmentation, and invasive species were identified as "high priority" management issues for more than 80% of NETN parks (Table 1.7). The human population in the New England states was 2.5 times greater in 2000 than it was when the NPS was established in 1916 (US Census data 2000). With the doubling of the human population in New England came increasing pressure on space and natural resources and is the primary cause for natural resource issues in the Northeast. The construction and maintenance of roads is among the most widespread forms of habitat alteration (Trombulack and Frissell 2000) to natural communities and 82% of NETN parks identified car traffic as a management issue (Table 1.7). Roads affect terrestrial and aquatic ecosystems through increased mortality caused by collisions with vehicles (Groot Bruinderink and Hazebroek 1996), modification of animal behavior (Brody and Pelton 1989), spread of exotic species (Greenberg et al. 1997), and changes in soil and water chemistry (Trombulack and Frissell 2000). Parks and reserves in the northeast exist in a landscape matrix of developed or agricultural lands with some of the highest road densities in the U.S. Most NETN parks were established for cultural resources but have now become important to the maintenance of biological diversity and ecological integrity in the urbanizing landscapes where they occur and many of them are threatened primarily by external impacts.

Land cover change and the associated threats to natural ecological communities associated with habitat fragmentation are a common theme among NETN parks. Habitats within landscapes are altered at varying levels of intensity as human demand for space and natural resources increases, leaving many landscapes, especially those where human populations are dense, in a fragmented state(Saunders et al. 1991). Habitat fragmentation can be manifest on the landscape via the direct loss of habitat, reduction in size of remaining patches, increased isolation, and loss of habitat diversity (Saunders et al. 1991). Most ecosystems in the northeast have experienced some level of habitat fragmentation, which has been implicated as a principal threat to most species in the temperate zone (Wilcove et al. 1986). Parks in the NETN, most of which were established for cultural resources, are relatively small in size and located in increasingly urbanizing landscapes. The role they play to the maintenance of regional biological diversity may, however, be substantial. (Falkner and Stohlgren 1997) conducted an analysis of the role of 44 NPS units in the Rocky Mountain region and found small, cultural parks contributed substantially to the conservation of regional biodiversity by acting as biological refugia, migration/dispersal rest stops and corridors, and living outreach programs. They indicated that small units had a disproportionate share of regional biodiversity and an understated role in the conservation of biodiversity in the region.

The ecological effects of invasive plant species were identified by most parks as a primary threat to park ecological communities (Table 1.7). We solicited parks for a list of the invasive plants known to occur within park boundaries to begin the process of identifying priorities for monitoring and management (Appendix E). Non-indigenous species spread at the rate of ≈ 700,000 hectares per year in the US with an impact on human economic systems estimated in the billions of dollars (Pimentel et al. 2001). Invasive species alter ecosystem structure, function, and species composition to such an extent that they threaten native flora and fauna. Non-native species are the second highest threat to the threatened and endangered species in the United States behind habitat loss. Of the 958 species listed, about 400 (42%) are threatened by non-native species (Pimentel et al. 2001).

The NETN parks share some common resource management issues, but also have park specific issues and management priorities (Table 1.7). Clearly, coastal issues are a concern for Acadia and Boston Harbor Islands and high elevation forests are a primary concern for the Appalachian Trail. Deer browsing, a significant stressor to many ecological communities was listed as a management priority for 5 parks. Within this survey, climate change was only identified as a natural resource issue for parks with coastal and high elevation habitats; however, climate change is expected to have substantial impacts over the long-term upon all NETN parks.

__Table 1.7.__ Potential natural resource threats to NETN parks (present or future) as indicated by natural resource staff. The level of each threat is identified by; 0 = not a threat, 1 = low threat, 2 = high threat w/ present mgt. concern. Categories were added during this process resulting in blank cells for parks that have not seen the additional categories at the time of this draft.

Potential Threats to Park Natural Resources	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
Air Quality											
Acid Deposition	2	2	1	2	1	2	1	2	1	1	1
Ozone	2	2	1	1	2	2	1	2	1	2	1
Visibility	2	2	1	1	1	2	1	1	1	1	1
External Development											
Cell/Wind Towers	2	2	0	1	2	2	1	2	0	2	1
Encroachment	2	2	1	2	2	2	2	2	0	2	2
Habitat Fragmentation	2	2	1	2	2	2	2	2	0	2	2
Marinas/moorings	0	0	1	0	0	0	0	0	0	1	0
Oil Spills	2	1	0	0	1	1	1	1	1	1	0
Pipeline operations	0	2	1	0	1	0	0	0	0	0	0
Residential/commercial	2	2	0	1	2	2	2	2	1	2	2
Roads	2	2	0	1	2	1	2	2	1	1	1
Septic Systems	2	0	2	0	1	2	2	2	0	1	2
Sound	1	2	1	0	2	2	1	2	1	1	2
Utility right of ways	1	2	0	0	1	0	1	1	1	0	1
Viewsheds	1	2	0	1	1	1	1	1	2	2	1
Night Sky	1	1	0	1	0	0	0	1	0	1	0
Visitor Impacts											
Boat Traffic	1	0	2	0	1	0	0	0	0	1	0
Car Traffic	2	1	1	0	2	2	1	1	0	1	2
Horseback riding	0	1	0	1	0	1	0	0	0	1	2
Over fishing	2	0	0	0	0	0	0	1	0	0	1
Soil compaction	2	2	1	1	1	1	1	1	0	0	2
Hiking Trail Impacts	1	2	2	1	1	1	1	1	0	1	1
Contaminants/Toxics											
PCB	1	1	1	0	1	1	1	1	1	2	0
Hg	2	2	1	0	1	0	1	1	1	2	0
Pb, Zn, Cd	1	2	1	0	0	0	0	0	0	2	0
Natural Disasters											
Droughts	1	1	1	1	1	1	1	1	1	1	1
Floods	0	1	1	0	1	1	1	1	1	1	0
Ice storms	1	1	0	1	1	1	1	1	1	1	2
Wind Events	1	1	2	1	1	1	1	1	1	1	1
Fire	1	1	0	0	0	0	0	0	0	1	0

Potential Threats to Park Natural Resources	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
Internal Park Development	1	1	1	0	0	0	1	0	1	1	0
Nuisance Wildlife											
Beaver	2	1	0	1	2	0	1	0	0	1	0
Raccoons	2	0	1	0	1	1	1	1	1	1	0
Fox	1	0	1	0	1	0	0	0	0	0	0
Feral cats/dogs	1	0	1	1	1	1	1	1	1	1	1
Canada geese	0	0	0	0	0	0	0	0	2	0	0
Woodchuck	0	0	0	0	0	0	0	0	0	0	2
Deer over browsing	0	1	0	2	1	2	2	1	0	2	2
Pest Species (parasites/pathogens)											
Asian Long-Horn Beetle	1	1	0	1	1	2	0	2	1	1	2
Gypsy Moth	1	2	0	1	2	2	1	1	1	1	1
Hemlock wooly adelgid	2	2	0	1	2	2	2	2	0	1	2
Lyme Disease	2	2	1	1	2	2	2	1	1	2	2
West Nile Virus	1	1	1	1	1	2	2	1	2	1	2
Chronic Wasting Disease	0	1	0	1	0	1	1	1	0	1	0
Water Quality											
Agricultural Runoff	1	1	0	1	1	0	0	2	0	1	0
Eutrophication	2	1	0	1	1	0	1	2	2	1	1
Land use change	2	2	0	0	2	2	2	2	2	2	1
Non-point pollution	2	1	2	1	1	2	2	2	2	1	1
Nutrient Loading	2	1	2	1	1	0	2	2	2	1	1
Point pollution	1	2	2	0	1	2	0	1	2	0	0
Road Runoff	1	1	0	1	1	1	1	2	2	1	1
Sedimentation	1	1	1	2	1	1	1	2	2	1	1
Stream bank erosion	1	1	0	1	1	1	0	2	1	1	1
Wastewater treatment	0	1	1	0	1	0	1	0	2	0	0
Climate Change											
Coastal erosion	1	0	2	0	0	0	0	0	0	0	0
Alpine recession	2	2	0	0	0	0	0	0	0	0	0
Sea level rise	1	0	2	0	0	0	1	0	1	0	0

1.5 Summary of Existing Park and Adjacent Monitoring Programs

We solicited information from park resource managers regarding current and historical monitoring efforts within NETN parks to identify opportunities to continue, modify, or expand existing programs. Air quality monitoring within a park is only occurring at Acadia, a designated Class 1 air quality area. Air quality around other network parks is ongoing and conducted by other programs (Appendix F). Acadia, Morristown, Roosevelt-Vanderbilt, Saint-

Gaudens, and Saugus Iron Works currently have water-quality and (or) water-quantity monitoring programs (Appendix G). Boston Harbor benefits from a monitoring program conducted by the Massachusetts Water Resources Authority (MWRA). Water quality monitoring programs are summarized in the water quality Phase I scoping report (Appendix G). The period of data collection varies; some monitoring programs were initiated as early as the 1970s and some as recently as 1998. The parks that do have monitoring programs primarily include measures in the vital sign of water chemistry. Additionally, Acadia, Morristown, Roosevelt-Vanderbilt, and Saint-Gaudens, have some form of invertebrate monitoring in streams. The protocols for these monitoring programs vary among parks. The remaining four parks (Marsh Billings, Minute Man, Saratoga, and Weir Farm) have no known current freshwater-quality monitoring at present (2004). Morristown and Saratoga, two parks with ecological issues caused by over-abundance of deer, have ongoing deer population monitoring (Appendix H). Acadia, Appalachian Trail, and Morristown have specific threatened and endangered species monitoring programs, and Marsh-Billings-Rockefeller and Saint-Gaudens have ongoing forest monitoring programs (Appendix H).

Data collected as a part of pre-existing monitoring programs will provide historical comparisons and context for the data collected by the NETN vital signs program. In some cases, the NETN monitoring program will build on the program currently in place, especially where measures, sampling locations, and/or sampling protocols are similar across programs. In other cases, however, compatibility will vary because the monitoring programs at some of the parks are focused on specific resources or have different objectives than the vital signs program.

To help us develop partnership opportunities with monitoring efforts being conducted by other federal and state agencies, we also reviewed national, regional, and local monitoring efforts that may be relevant to natural resource monitoring in our network. These 'outside the parks' monitoring efforts and available weather stations are summarized in Appendices I and J.

1.6 Goals and Objectives for the NETN Program

Based on our current knowledge of the ecological systems, threats and park resources of the NETN, and the overall goals of the NPS Vital Signs program (Section 1.3.2), we can now outline a series of goals and objectives that guide the development of vital signs and measures. These goals and objectives are still in draft form and will be refined over time in consultation with others and through peer review.

Goal A. *–Drivers and Stressors-* Monitor the status and trends of selected ecological drivers and anthropogenic stressors acting upon NETN ecological systems, to support and inform management decisions.

Objective A.1. Monitor the response of ecological systems to natural disturbances and, where possible, compare to historical responses.

Objective A.2. Detect new invasive plant and animal species before they become a long-term management issue.

Objective A.3. Monitor changes in adjacent land cover and land use to assess the potential impacts from adjacent human activities on park ecosystems.

Objective A.4. Provide accurate meteorological information to all parks to be used as a correlate to aid in understanding trends in other monitoring indicators.

Objective A.5. Summarize existing atmospheric deposition and ozone information and apply these data to better understand their impacts on park ecosystems.
Objective A.6. Monitor the biotic and abiotic response to climate change, including phenological shifts in terrestrial systems and shoreline changes in coastal systems.
Objective A.7. Establish a baseline on white-tailed deer browse intensity for each NETN park and track the level of browse intensity over time.
Objective A.8. Assess role of visitor use in different units of the park, and their impacts on species and ecological systems.

Goal B. – *Species, Ecosystem Structure and Processes, and Ecological Integrity* - Monitor the status and trends of selected taxa and ecological system structure and processes within NETN parks, to support and inform management decisions affecting those taxa and processes. Identify key components of ecological integrity within NETN ecological systems and monitor these components to determine status and trends of NETN systems, in order to support and inform management decisions affecting those ecological systems.

Objective B.1. Monitor status and trends of focal taxa across a broad taxonomic range.
Objective B.2. Monitor status and trends of specialized habitats, such as vernal pools.
Objective B.3. Monitor hydrologic dynamics, especially water quantity, in freshwater aquatic and intertidal systems.
Objective B.4. Monitor changes in forest, wetland, and high elevation vegetation condition, structure, and composition to determine the effects of multiple stressors acting on these systems.
Objective B.5. Monitor changes in the extent and condition of ecological systems within NETN parks.
Objective B.6. Monitor core abiotic and biotic water quality indicators within the primary aquatic resources for each network park.
Objective B.7. Inventory stream geomorphology and lakes morphometry to establish a baseline to better interpret water quality monitoring data.

Goal C. – *Communication and Reporting* - Summarize and communicate the ecological integrity of NETN systems using a combined approach reporting both statistical trends and qualitative ecological integrity ratings.

Objective C.1. Use statistical tools to assess status and trends of vital signs.
Objective C.2. Use selected vital signs and available baseline information to assign and assess change to ecological integrity rankings.
Objective C.3. Use statistical tools and ecological integrity scorecard to inform decision-making processes for park natural resource management.

Goal D. -*Special Park Resources*-. Provide information directly related to special park resource management issues.

Objective D.1. Monitor forest and old-field habitats to determine how best to maintain focal park resources.

Chapter 2: Conceptual Ecological Models

2.1 Introduction

The development of conceptual ecological models to identify key system components, linkages and processes is a critical step in the design of a long-term monitoring program. The need for conceptual ecological models has been well established by many (National Research Council 2000, Elzinga et al. 2001, Noon 2002), including the NPS prototype park monitoring program. Conceptual models improve the planning process for monitoring by explicitly stating key elements of our understanding of system dynamics, which facilitates discussion, evaluation and refinement of the monitoring program (Maddox et al. 1999). Given the complexity of natural systems and the variety of factors that influence ecological processes, there is an obvious need for conceptual modeling as a tool to help organize information and synthesize understanding of system components and interactions. Failures in the development of major ecosystem monitoring programs have been attributed to the absence of sound conceptual models (National Research Council 1995).

As outlined in Chapter 1 of this document, the NPS Vital Signs Monitoring Program seeks to facilitate adaptive management by monitoring status and trends in 1) the ecological condition of park resources, 2) key anthropogenic stressors acting upon park systems, and 3) focal park resources. To accomplish this three-pronged objective, NETN has chosen to develop conceptual models which are both "effects-oriented" and a "predictive or stressor-oriented" (Trexler and Busch 2002). In other words, NETN conceptual models incorporate elements of ecological integrity, which integrate the effects of multiple drivers and stressors acting upon a system over time, as well as specific anthropogenic stressors and focal park resources.

A useful conceptual model or set of models for the NPS Vital Signs Monitoring Program should attempt to accomplish the following:

- Identify the bounds and scope of the system of interest;
- Conceptualize and synthesize current understanding of system dynamics;
- Identify major drivers and stressors acting upon the system and present our current understanding of system responses;
- Integrate across disciplinary boundaries and spatial scales;
- Describe and illustrate alternative hypotheses about key processes or system dynamics.
- Aid in identifying appropriate indicators of ecological integrity and stressors;
- Identify and illustrate key relationships among indicators and system dynamics;
- Identify knowledge gaps which indicate the need for additional research;
- Be updated as new information improves our understanding of the system;
- Facilitate communication among scientists from different disciplines, managers, policy-makers, and the public.

Given these lofty aspirations, it is important to remember that conceptual models are merely abstractions of our current understanding of the system. In reality, ecological systems are far too complex to be fully represented by our models. Moreover, these models must be flexible enough to allow change over time as our knowledge grows. Perhaps the most important characteristic of good conceptual modeling is the final point listed above: conceptual models foster communication and understanding among people with different backgrounds, goals, and points of view (Abel et al. 1998).

2.2 NETN Conceptual Model Development

2.2.1 Model Framework

Conceptual models may take the form of any combination of diagrams, narratives, tables, or matrices. In the development of conceptual models for the NETN Vital Signs Monitoring Program, we have chosen to employ both diagrammatic conceptual models, which help visualize system components and interactions, as well as narratives, which provide additional detail describing our current understanding of system components and interactions.

We have chosen a hierarchical approach to model development, beginning with a general model for the each of four key NETN ecological system groups (terrestrial, wetland, aquatic and intertidal). These general models identify key ecosystem drivers, stressors, ecological processes, elements of ecosystem (abiotic and biotic) condition, and focal park resources acting upon or present within each of these four major system groups. We present these general models herein as diagrams accompanied by detailed narratives, which lay out our current understanding of each of these components and their interactions.

A set of two diagrammatic models is then developed for each NETN park, which more specifically illustrate the specific stressors acting upon the ecological systems and aquatic resources, respectively, present within each park. These park models are included in Appendix K. The aquatic park models include a hydrologic model of the freshwater inflows and outflows present in the park, as well as information describing freshwater resources. The aquatic models assume that ecosystem-wide processes such as precipitation and evaporation occur throughout the park, and that ground-water/surface-water interactions occur in both directions and also throughout the park.

This nested set of conceptual models incorporates multiple spatial scales that may be of interest to mangers. Landscape-, park-, stand- and species-level elements are all represented herein. Moreover, these models employ the tools and expertise of a range of scientific disciplines: landscape ecology, biogeochemistry, forest ecology, wetland ecology, aquatic ecology and conservation biology.

2.2.2 Identification of Key Model Components

An important step in the development of NETN conceptual models was the careful consideration of all known stressors affecting ecological systems within NETN parks. This "threats analysis" initially considered the potential threats to NETN parks identified within Table 1.7; we then broadened the analysis to consider additional threats identified by the environmental science community, such as harvesting within the intertidal zone, additional taxa of invasive exotic species, such as earthworms and plants, and the broader effect of global climate change. Within the Conceptual Ecological Models we present in this chapter, we include key stressors known or believed to have significant ecological consequences on NETN ecological systems. We have chosen not to include some threats identified in Table 1.7 which are believed not to have significant ecological consequences in these systems; these include visibility impairment due to poor air quality and light pollution (dark night sky), viewshed issues and cell tower development nearby parks, noise (sound) within parks, some populations of native wildlife, such as raccoons, fox, and woodchuck, and several diseases, such as Lyme disease, West Nile Virus and Chronic Wasting Disease. Several of these “threats” impact visitor experience and thus are important park issues, but are better addressed by other NPS programs. Other issues affect the ecology of the park, but to a much lesser extent than those stressors considered herein.

It is worth noting here that mandated species, or rare, threatened and endangered species that receive legal protection, are an important focal park resource that was considered for inclusion in the NETN Vital Signs program. They were not selected for inclusion because mandated species provide little insight into park ecological integrity, and they are not discussed further herein.

2.2.3 Definitions

We have used the following terminology in developing NETN conceptual models:

Ecosystem drivers are major external driving forces such as climate, hydrology, and natural disturbance regimes (e.g., hurricanes, droughts, fire) that have large-scale influences on natural systems.

Stressors are physical, chemical, or biological perturbations to a system that are either foreign to that system, or natural to the system but applied at an excessive or deficient level (Barrett et al. 1976). Stressors cause significant changes in the ecological components, patterns and processes within natural systems. Examples include water withdrawal, invasive exotic species, landuse change, and air pollution.

Focal park resources are resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of current threats or whether they are indicative of ecosystem integrity.

Focal taxa are taxa that, by virtue of their sensitivity or exposure to stress, their association with other taxa, or their life history characteristics, might serve as useful indicator species of ecological integrity. While the concept of focal taxa differs substantially from focal park resources (defined above), some taxa fall into both categories.

Ecological integrity is a concept that expresses the degree to which the physical, chemical, and biological components (including composition, structure, and process) of an ecosystem and their relationships are present, functioning, and capable of self-renewal. Ecological integrity implies the presence of appropriate species, populations and communities and the occurrence of ecological processes at appropriate rates and scales as well as the environmental conditions that support these taxa and processes.

Indicators are a subset of measurable ecosystem features or processes that are particularly information-rich in that their values are indicative of the quality, health, or integrity of the larger ecological system to which they belong (Noon 2002). Indicators are a select subset of the physical, chemical, and biological elements and processes of natural systems that represent the overall health or condition of the system.

Vital Signs, as used by NPS, are indicators selected to represent the overall health or condition of park resources, known or hypothesized effects of stressors, or elements that have important human values. Vital signs may occur at any level of organization including landscape, community, population, or genetic level, and may be compositional (referring to the variety of elements in the system), structural (referring to the organization or pattern of the system), or functional (referring to ecological processes).

2.3 NETN Climate

Climate is a key ecosystem driver that affects the structure, composition and function of all ecological systems. The northeastern U.S. has a temperate humid continental climate (Trewartha and Horn 1980); this climate displays large daily and seasonal temperature variation and abundant rainfall evenly distributed throughout the year (Bryson and Hare 1974). Temperature and rainfall vary across the region along latitudinal and altitudinal gradients. Mean annual temperatures range from about 11˚ C along the southern coast to 4˚ C in the northern highlands and annual precipitation ranges from 90-120 cm, of which from 10 to 30% falls as snow (Bryson and Hare 1974). The northern part of this region experiences cool summers, and long, cold winters which typically include a persistent snowpack from mid-December until April. In the southern part of this region, summers are warmer, winter temperatures are milder and snowpack development is more variable. The number of freeze-free days annually varies from only about 90 in the White Mountains of New Hampshire and Maine to as many as 180 in a narrow strip along the southern coast (Bryson and Hare 1974). The climate of coastal regions is strongly influenced by the ocean; temperatures are more moderate and annual rainfall is slightly higher along the coast, and summer fog is common along the Maine coast. The Northeastern U.S. is in the path of many frontal systems; these typically move eastward across the continent until reaching the Atlantic Ocean then travel northeastward along the coast. Low pressure cells in the frontal systems generate counterclockwise winds that being warm, moist air from the Atlantic Ocean onto the mainland (Maloney and Bartlett 1991). Rain or snow is released when a warm air mass meets a cold front.

2.4 Terrestrial Resource Conceptual Model

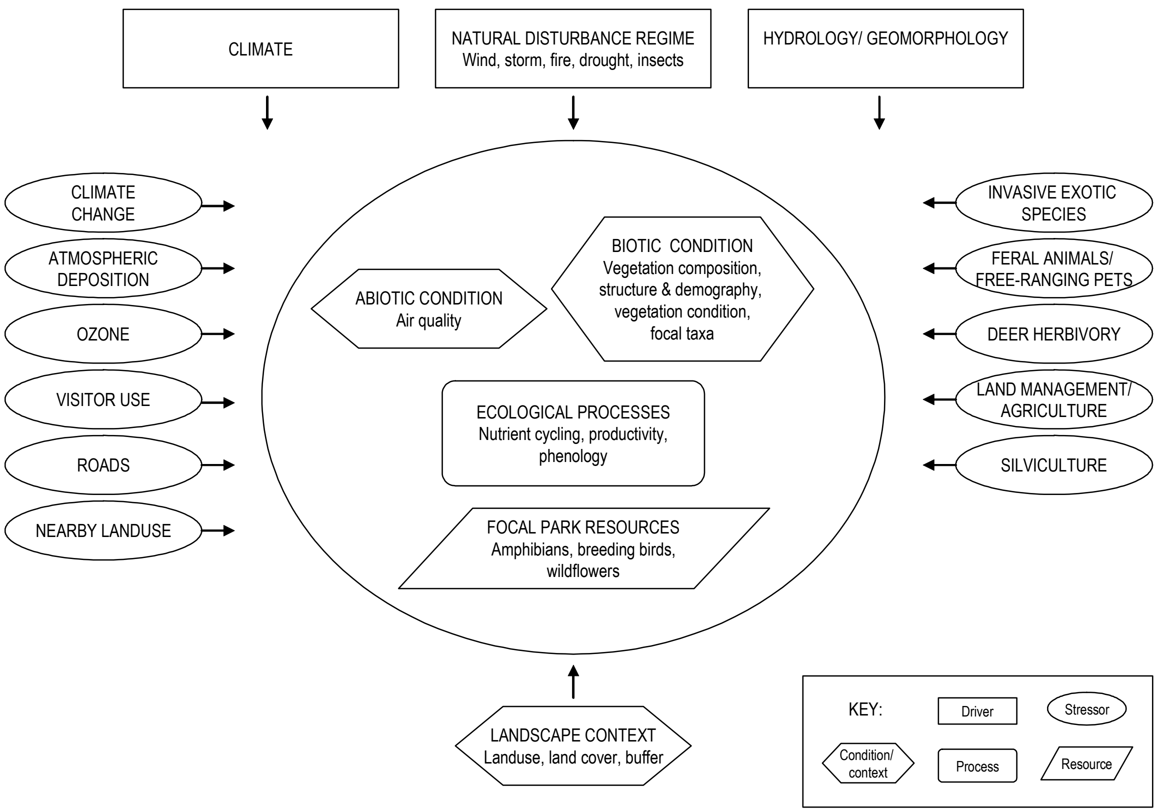
As described in section 2.2, we have developed a conceptual ecological model to identify key ecosystem drivers, stressors, ecological processes, elements of ecosystem (abiotic and biotic) condition, and focal park resources present within or acting upon each of four general ecological system groups present within NETN. Herein, we present the terrestrial resource conceptual ecological model as a diagram (Figure 2.1) accompanied by the following narrative describing our current understanding of these components and their interactions.

2.4.1 Ecological Systems

Terrestrial ecological systems present within NETN parks encompass a variety of forested systems and several types of open uplands and human-modified systems (Table 2.1). Within the northeastern US, a temperate climate with abundant rainfall acting on gently rolling and occasionally mountainous topography upon mostly acidic bedrock and glacial till creates suitable conditions for a variety of terrestrial vegetation. The topography and ecology of this region reflects its glacial history, which left a varied landscape of lakes, depressions, morainic hills, drumlins and other glacial features. While fine-scale variation in site conditions and natural disturbance create a diverse patchwork of varied forest associations, broad-scale patterns are evident. Latitudinal and altitudinal variation in temperature, soil quality and disturbance regimes from the coast up into the mountainous regions of New Hampshire, Vermont, and western Massachusetts create the broad ecological system groups described below. These general groups include a variety of more specific terrestrial ecological systems (NatureServe 2003a, b) described in Appendix C. The extent of these terrestrial systems within NETN parks is outlined in Table 2.1, and visually represented within the park-based Conceptual Ecological Models presented in Appendix K.

Figure 2.1 Conceptual Model for Terrestrial Systems

Forest, Open uplands, Alpine zone, Rocky shore, Plantation, Old-field successional, Field



Forested ecological systems within NETN parks can be divided into three general groups (Westveld 1956, Foster 2004): 1) the Central hardwood forests of southern New England and parts of New Jersey and New York, dominated primarily by oaks with other hardwood species; 2) the Northern hardwood forests of northern New England, dominated by American beech, yellow birch and sugar maple, with a variety of other hardwood species and hemlock and white pine; and 3) the Spruce-fir forest found at higher elevations in northern New England and along the Maine coast, dominated by red spruce and balsam fir, with white and black spruce. This Spruce-fir forest is often replaced after major disturbance by a Boreal aspen-birch forest. Within central New England, a broad transition zone exists in which oaks and hickories of the central hardwood forest intermingle with northern hardwood species.

Table 2.1. *Approximate extent (hectares) of NatureServe terrestrial ecological systems present within NETN parks. This information will be updated and improved after completion of the I&M mapping inventory of these parks. Area listed in larger boxes spanning more than one ecological type indicates that current information does not distinguish between related types. Most BOHA terrestrial communities have yet to be classified and are listed here as "other"; information for APPA is not yet available. Descriptions of these ecological system types can be found in Appendix C.*

<table>
<tr><th>Ecosystem Category</th><th>NatureServe Ecological System Type</th><th>ACAD</th><th>BOHA</th><th>MABI</th><th>MIMA</th><th>MORR</th><th>ROVA</th><th>SAGA</th><th>SAIR</th><th>SARA</th><th>WEFA</th></tr>
<tr><td>Spruce-fir forest</td><td>Acadian Lowland Spruce-Fir-Hardwood Forest</td><td>6588</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">Northern hardwoods/ mixed forest</td><td>Boreal Aspen-Birch Forest</td><td>1160</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Laurentian-Acadian Northern Hardwoods Forest</td><td>314</td><td></td><td>33</td><td>20</td><td></td><td>83</td><td>13</td><td></td><td>273</td><td>1</td></tr>
<tr><td>Laurentian-Acadian White Pine-Red Pine Forest</td><td>737</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Laurentian-Acadian Pine-Hemlock-Hardwood Forest</td><td>881</td><td></td><td>97</td><td></td><td></td><td rowspan="2">77</td><td>19</td><td></td><td rowspan="2">432</td><td></td></tr>
<tr><td>Appalachian Hemlock-Hardwood Forest</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Central Appalachian Oak and Pine Forest</td><td></td><td></td><td>1</td><td></td><td rowspan="2">229</td><td></td><td></td><td></td><td></td><td rowspan="2">20</td></tr>
<tr><td rowspan="2">Central hardwoods forest</td><td>Northeastern Interior Dry Oak Forest</td><td></td><td></td><td></td><td>112</td><td>3</td><td></td><td></td><td></td></tr>
<tr><td>Central and Southern Appalachian Northern Hardwood Forest</td><td></td><td></td><td></td><td></td><td>44</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Open uplands</td><td>Laurentian-Acadian Acidic Rocky Outcrop</td><td>3295</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Laurentian-Acadian Calcareous Rocky Outcrop</td><td></td><td></td><td></td><td></td><td></td><td>0.04</td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Cliff and talus</td><td>Laurentian-Acadian Calcareous Cliff and Talus</td><td></td><td></td><td>0.2</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Laurentian-Acadian Acidic Cliff and Talus</td><td>11</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Rocky shore</td><td>Acadian-North Atlantic Rocky Coast</td><td>116</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="6">Modified</td><td>Native Plantation</td><td></td><td></td><td>45</td><td></td><td></td><td>2</td><td>11</td><td></td><td>4</td><td></td></tr>
<tr><td>Exotic Plantation</td><td></td><td>4</td><td>18</td><td></td><td></td><td>12</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Old-field successional</td><td></td><td>36</td><td>3</td><td>62</td><td>193</td><td>15</td><td></td><td></td><td>162</td><td></td></tr>
<tr><td>Open fields</td><td></td><td></td><td>17</td><td></td><td>24</td><td></td><td>6</td><td></td><td></td><td>6</td></tr>
<tr><td>Agricultural fields</td><td></td><td></td><td></td><td>42</td><td></td><td>8</td><td></td><td></td><td>206</td><td></td></tr>
<tr><td>Landscaped grounds</td><td>112</td><td></td><td>4</td><td>14</td><td></td><td>50</td><td>2</td><td>1</td><td>5</td><td></td></tr>
<tr><td colspan="2">Other</td><td></td><td>104</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Relatively open vegetation communities occur within NETN at high elevations, upon steep slopes and along the coast. These systems are primarily present along the APPA and within ACAD. These open uplands can be classified generally into four categories: 1) open upland outcrops of oak and pine woodlands and shrublands, often accompanied by low heath shrubs, which occur on and around rocky summits; 2) alpine zone barrens which occur above treeline along the APPA and are characterized by dwarf shrubs, lichens, and areas of sparse vegetation; 3) sparsely vegetated cliff and talus systems which develop near steep cliffs and include the dry, exposed talus slopes that develop beneath the cliffs; and 4) patchy shrub vegetation on rocky shores, which develops within the narrow strip just above the high tide line along the New England coast where tree growth is inhibited by wind, salt spray and fog.

Several human-modified terrestrial habitat types occur within NETN parks. Native and/or exotic tree plantations have been established at MABI, ROVA, and to a lesser extent, at other parks. Successional old-field habitat, maintained open fields and active agricultural fields are all present within the historic parks, which are managed to perpetuate historical landscapes. Finally, some area of landscaped grounds is present within most NETN parks.

The presence of one rare terrestrial community type has been confirmed at ACAD; the Pitch pine/Broom crowberry woodland is ranked G1/G2 by NatureServe, indicating this community type is globally imperiled or critically imperiled.

2.4.2 Ecosystem Drivers

2.4.2.1 Climate

Climate is a key ecosystem driver that affects ecosystem structure, composition and function. The climate of the northeastern U.S. is described above within section 2.3. Temperature and rainfall vary latitudinally and altitudinally across the region creating gradations between the Central and Northern hardwood and Spruce-fir forests, and the open and alpine uplands. The potential and realized impacts of changing climate upon terrestrial systems within NETN parks are described below within section 2.4.7.

2.4.2.2 Disturbance Regimes

Disturbance regimes are a second key driver affecting NETN terrestrial systems. The forces of disturbance work upon this forested landscape to create a shifting mosaic of forest regeneration and succession. Throughout the entire region, frequent windstorms create small- to medium-size gaps that rapidly regenerate; these windstorms are more frequent along the coast and on windward slopes (Lorimer and White 2003). Less frequent hurricanes create much larger openings and temporarily create habitat for earlier successional species within the forest mosaic. Periodic ice storms can cause substantial damage over large regions, but tend to result in regeneration rather than stand replacement (Lorimer and White 2003). The natural role of fire within this region is complex and less well understood. Historically, fire has been infrequent within the northern hardwoods forest, but was more common within the central hardwoods forest and probably also within the transitional mixed forest between northern hardwoods and spruce-fir (Cogbill et al. 2002). At the time of European settlement, the central hardwood oak forests of the southern New England coast were more open forests with sparse understory, perhaps due to propagation of fire by native Americans (Cogbill et al. 2002). European settlement drastically increased the frequency and intensity of fires throughout the northeastern U.S., particularly due to logging and railroad traffic during the 19th century. Much of Acadia National Park burned during a historic fire in 1947. Modern fire suppression regimes have now essentially removed fire as an agent of disturbance in this region. Insect pests and disease are also important agents of natural disturbance, particularly in the low diversity coniferous forest. The native spruce budworm has periodically killed large numbers of mature balsam fir which then blowdown or burn creating large-scale disturbance (Lorimer and White 2003). Additionally, individual trees periodically succumb to disease or senescence, contributing to the gap dynamics of these forests.

Disturbance regimes within terrestrial systems are best considered at multiple scales. Infrequent, larger-scale disturbance is evident at the scale of the landscape and can be monitored using remote sensing. More frequent, smaller-scale disturbance is evident at the scale of the stand and can be monitored on-site. The potential and realized impacts of altered disturbance regimes due to climate change and invasive exotic species are discussed below within section 2.4.7.

2.4.2.3 Hydrology/Geomorphology

As noted above in section 2.4.1 and below in sections 2.5 and 2.6, the hydrology and geomorphology of the area create conditions suitable for terrestrial ecosystems and the wetland and aquatic systems that exist within them. Vital Signs of these drivers are discussed within the Wetland and Aquatic Conceptual Ecological Model sections.

2.4.3 Abiotic and Biotic Condition

Air quality is an important element of abiotic condition affecting terrestrial ecosystems. This parameter is discussed in some detail below in the section describing stressors (2.4.7).

Monitoring biotic condition is critical to understanding the ecological integrity of ecosystems subjected to multiple stressors. Within terrestrial ecosystems, the structure, composition and condition of dominant vegetation play a key role in determining ecosystem function and quality of habitat for other species. For this reason, monitoring key elements of vegetation structure, composition and condition are particularly important elements for long-term monitoring. In addition, NETN has attempted to identify taxa that may be useful indicators of the condition of particular functional or taxonomic groups or of response to specific stressors. While the use of focal taxa as indicators of ecological condition is controversial (Prendergast et al. 1993), this approach can be useful if a range of species representing diverse taxa and various life histories can be included (Terborgh 1974, Griffith 1997, Carignan and Villard 2002). By monitoring diverse taxa, we reduce the chance of failing to detect significant change in the ecological integrity of these systems. In theory, it is attractive to select a parsimonious set of "best" indicators of ecological condition for these systems; in reality, we must realize that our current understanding of ecological systems is limited, and that a narrowly-focused monitoring program will fail to detect change within many important but less-charismatic taxa.

2.4.3.1 Vegetation Composition, Structure and Demography

Vegetation composition, structure and demography are fundamental properties of terrestrial ecosystems. Monitoring the composition and structure of forest communities provides basic information on changes in forest cover type, species composition, and the type and quality of available wildlife habitat; moreover this basic information will allow proper interpretation of many other Vital Signs. Monitoring vegetation demography in the form of tree seedling and sapling regeneration provides an anticipatory indicator of future forest cover type as well as an integrative measure of the impacts of multiple stressors acting upon vegetation. Monitoring canopy and understory tree growth and mortality provides additional key integrative measures of multiple stressor impacts. Stand structural or age class is indicative of both successional stage and habitat quality, and is a particularly useful measure in forest systems subject to silviculture. Legacy features, such as large trees, snags and coarse woody debris provide important habitat for birds, mammals, and herptiles, as well as decomposers, bryophytes and tree seedlings. These legacy features can be useful indicators of wildlife habitat within early- and mid-successional forests and those subject to silviculture.

2.4.3.2 Vegetation Condition

Canopy vegetation condition is an integrative, anticipatory indicator of stress and change within canopy vegetation, which can in turn lead to changes in ecosystem function, habitat quality and stand composition. Canopy condition can be affected by a multitude of drivers and stressors, including climate, outbreaks of insect pests or disease, atmospheric deposition, tropospheric ozone pollution, and nutrient availability (Bonneau et al. 1999, Shugart et al. 2000). Canopy vegetation condition can be measured across the landscape using vegetation stress indices from hyperspectral remote sensing (Sampson et al. 2000, Miles et al. 2003). While hyperspectral imagery is currently expensive to obtain, this technology is advancing rapidly and should be considered for inclusion in the NETN monitoring program as affordable imagery becomes available. At the stand scale, canopy condition can be assessed visually onsite as the crown condition of each canopy tree in a plot.

2.4.3.3 Focal Taxa

Selection of focal taxa as indicators for long-term monitoring should, to the extent possible, detect response to a wide range of stressors at several spatial scales (Noss 1990, O'Connell et al. 1998), and include the range of functional and taxonomic groups important in a particular ecosystem (Terborgh 1974, Keddy and Drummond 1996, Griffith 1997, Carignan and Villard 2002). Monitoring of taxa with specific functional relevance, such as pollination and decomposition, would incorporate indicators of these important ecological processes into NETN ecological integrity ratings. Within temperate forested ecosystems, mycorrhizal fungi, arthropod pollinators and decomposers, are key taxa performing essential ecosystem functions.

Ectomycorrhizal fungal communities have been shown to be sensitive to nitrogen deposition, a key component of acidic deposition (Arnolds 1991, Lilleskov and Bruns 2001). While short-term trends in ectomycorrhizal sporocarp emergence exhibit substantial temporal variation due to climatic fluctuations and other factors, long-term data collection may allow the elucidation of trends in the relative change in functional groups of ectomycorrhizae from sporocarps (Lilleskov, personal communication).

Selected arthropod taxa could provide useful indicators of environmental condition at the scale of the park. In general, arthropods inhabit smaller home-ranges than many larger and more charismatic fauna, and so may be useful as indicators of environmental condition within these relatively small parks. Moreover arthropods typically have shorter lifespans than larger faunal taxa, which may increase their utility as "early-warning" indicators. Studies have shown that carrion beetles are sensitive to forest fragmentation (Gibbs and Stanton 2001); these beetles are important decomposers, and are straightforward to monitor. Honeybees are another taxa with important functional relevance that may be feasible for inclusion in a long-term monitoring program (Sam Droege, personal communication).

Additional focal taxa which may be useful to incorporate in a long-term monitoring program are high-profile "flagship" taxa which are also sensitive to anthropogenic stressors. In this capacity, avian communities may be particularly well-suited to long-term monitoring due to their sensitivity to habitat fragmentation, and the ease of avian identification using vocalization (Carignan and Villard 2002). Additionally, temperate forests are known for their diverse herbaceous communities, which are highly visible and taxonomically well-known. Finally, the red-backed salamander comprises a significant component of faunal biomass within temperate forested systems, in which it is widely distributed. This species has been monitored as an indicator of acid stress and climate change (Welsh and Droege 2001).

In addition to forested ecosystems, NETN parks contain substantial areas of open field and successional old-field habitat, which is maintained within many NETN historic parks to satisfy cultural mandates. While highly modified, these systems provide important habitat for many grassland and shrubland species, such as the upland sandpiper, Henslow's sparrow, grasshopper sparrow, savannah sparrow, bobolink and Eastern meadowlark (Bernardos et al. 2004). These birds proliferated within the agrarian landscape of nineteenth and early 20th century New

England, and populations of these birds have declined significantly as the landscape has reforested over the last century. Thus the national historic parks provide essential habitat for these vulnerable species.

2.4.4 Ecological Processes

2.4.4.1 Nutrient Cycling

Nutrient cycling is a fundamental ecological process that is intrinsically linked to the composition, productivity and function of ecosystems. The utility of using some measures of nutrient cycling as indicators of ecosystem status, function or integrity has been widely recognized (Harwell et al. 1999). Plant growth in northeastern forested ecosystems has historically been limited by nitrogen, an essential macronutrient in limited supply. Anthropogenic atmospheric deposition of nitrogen compounds has altered patterns of nitrogen cycling in northeastern forests, increasing both the supply of available nitrogen and nitrate loss from the system, a trend which may lead to nitrogen saturation and increased acidification (Aber et al. 1998). Acidic deposition has also caused the loss of essential base cations from terrestrial systems via leaching, and has increased availability within the soil of aluminum – a phytotoxin (Driscoll et al. 2001a). Monitoring a few simple measures of terrestrial N cycling (nitrification, soil C:N ratio) and base cation and aluminum availability (soil base saturation and Ca:Al ratio) will provide useful information indicating the level of stress from atmospheric deposition experienced by forested systems (Driscoll et al. 2001b). Additionally, monitoring of nitrate in streamwater across the landscape will allow some assessment of patterns and degree of nitrogen saturation.

2.4.4.2 Productivity

Ecosystem productivity provides a measure of energy flow through the system; productivity is the amount of energy stored as organic matter. Patterns of productivity are strongly dependent upon temperature, rainfall, and solar radiation, thus productivity varies with vegetation physiognomy. Within an ecological system, annual productivity varies with climate and patterns of disturbance as well as with stressors such as insect or herbivore browsing and atmospheric deposition and ozone (Ollinger et al. 2002, Laurence and Andersen 2003). Thus productivity provides an integrated measure of the status of an ecological system or of specific taxa. Forest productivity can be measured via remote sensing using indices of chlorophyll concentration (Sampson et al. 2000, Smith et al. 2002), or from stand measurements of forest growth.

2.4.4.3 Phenology

Northeastern temperate systems are characterized by distinct seasonality that drives patterns of floral and faunal phenology. Recent research indicates that anthropogenic climate change may already be driving phenological change in a variety of species (Parmesan and Yohe 2003, Root et al. 2003). Monitoring key phenological occurrences such as bud break and flowering in key species will help determine the magnitude and patterns of such change within NETN systems. This Vital Sign is particularly well suited to implementation at APPA, which exhibits broad climatic variation along its extensive latitudinal and altitudinal gradients.

2.4.5 Focal Park Resources

Several focal taxa discussed above as components of biotic condition are also focal park resources; amphibians, breeding birds, and wildflowers (a subcomponent of forest herbs) are all taxa that have broad appeal to the public and thus receive attention from NPS. The use of these taxa as Vital Signs is discussed above in section 2.4.3.

2.4.6 Landscape Context

The landscape of New England has been profoundly altered by human activities over the last four hundred years (Foster et al. 2004). Widespread clearing for agriculture and logging for timber have left very few terrestrial systems in the northeastern U.S. untouched. In particular, the southern New England coast and adjacent areas of New York and New Jersey are among the most densely settled areas within the U.S., resulting in the elimination or drastic alteration of all of the central hardwoods forest within this region. Remaining areas are small, fragmented and heavily impacted by human activities. Larger areas of northern hardwood forest, and spruce-fir forest remain within central and especially northern New England. Most of these areas were logged, or cleared and plowed during the 19th century, and some have now returned to “mature” forest that in some ways resemble pre-settlement forest, while others are currently managed for timber production.

Remaining natural areas exist in a matrix of managed, rural, and suburban habitat that limits the ability of species to interbreed and disperse, introduces “edge effects” and allows “encroachment” of anthropogenic influences. A network of roads cuts through the northeast, reinforcing edges and introducing disturbance, pollutants, de-icing chemicals, and facilitating invasion by exotic species (Brothers and Spingam 1992, Spellerberg 1998). Compared to forest interiors, forest edges are windier, subject to greater extremes in temperature, are more accessible to specific predators, and receive higher loads of some atmospheric pollutants (Harrison and Bruna 1999, Weathers et al. 2001). A large and growing body of scientific literature documents the negative impacts of habitat fragmentation on biodiversity in a wide variety of ecological systems (Fahrig 2003). The impacts of fragmentation have been especially well documented upon avian communities, and population declines of a variety of forest interior avian species are linked to habitat fragmentation (Rich et al. 1994, Austen et al. 2001). Habitat fragmentation is increasingly being monitored using remote sensing, and a wide variety of indices are available to describe patterns of fragmentation. Landscape buffers can help mitigate these outside influences.

2.4.7 Stressors

The ecosystems of New England currently are subjected to a suite of anthropogenic stressors unlike anything encountered during their long history prior to European settlement. These stressors act as agents of change in a myriad of related and often interacting ways. While the effects of some stressors, like acidic deposition, have been extensively studied and are well understood (Driscoll et al. 2001a), the effects of other important stressors, like climate change, are complex and unpredictable enough to elude our understanding despite concerted and ongoing study (McNulty and Aber 2001). The impacts of still other stressors, such as many newly invading species, are yet to be studied. The impacts of many stressors will vary depending upon landuse history (Foster et al. 2003), and the combined impact of this suite of interacting stressors is certain to yield unexpected results (Aber et al. 2001). In this section, we summarize knowledge about the effects of key stressors upon NETN terrestrial systems. The park-based conceptual ecological models within Appendix K reveal important stressors acting upon specific parks.

2.4.7.1 Invasive Species

The effects of invasive exotic species on the structure, composition and function of natural systems have become a chief concern of ecologists and land managers for the last 20 years (Drake et al. 1989). The spread of many invasive species is aided by disturbance and may increase as anthropogenic disturbance of native ecosystems continues to increase.

Currently, northeastern terrestrial systems are being seriously impacted by several species of invasive exotic insect pests and pathogens. The hemlock wooly adelgid has caused widespread mortality of hemlock across the eastern U.S. since introduction here in the 1950s, and threatens to rapidly and substantially reduce or eliminate eastern hemlock throughout much of its range (Orwig et al. 2002) which could have substantial impacts on associated taxa such as forest birds. Infestation currently extends into southern New England, but isolated occurrences further north indicate this pest will continue to spread. Only slightly less serious is the threat to American beech. An exotic scale insect has caused the widespread occurrence of beech bark disease throughout the northeastern forests. Caused by the interaction of this insect and a native fungus, beech bark disease has caused substantial beech mortality throughout the region, though most immature and some mature trees have some resistance to the disease. In areas of high beech mortality, increased sprouting of beech suckers can dramatically alter forest structure(LeGuerrier et al. 2003). Beech bark disease may substantially impact wildlife which rely on beech nuts. Another pest that has significantly impacted eastern forests since introduction in the late 19th century is the European gypsy moth. Currently distributed throughout the region, gypsy moth populations fluctuate; during eruptive years, large moth populations cause widespread defoliation of oaks, aspen, and many other trees, including white pine. Successive years of defoliation can kill trees, but annual tree mortality due to gypsy moth seldom exceeds 20% within a region (Morin et al. 2004).

Several other species pose substantial threats if they advance into the region. The Asian longhorned beetle is a large potential threat to maple and other tree species if it invades rural and forested areas from its current documented occurrences in and near New York City. Likewise, the Emerald ash borer is of high concern, though it has not yet been documented in the northeastern U.S. This insect quickly kills all native species of ash, and could have dramatic impacts if it arrives in this region. Finally, the fungal pathogen that causes sudden oak death has not yet been found in the eastern U.S., but could have dramatic impacts on oaks and other trees if unwittingly introduced into this region.

Another important taxa currently spreading through northeastern forests are invasive exotic earthworms. Where they occur, earthworms are “keystone” soil fauna which control many aspects of soil structure and nutrient cycling (Hendrix 1995). Native earthworms are rare in northeastern forests, presumably having been removed by glaciation (Gates 1970). Currently, several species of invasive exotic earthworms are spreading through northeastern forests, probably due to introduction by agriculture and fishermen, though the geographical extent of this invasion remains unknown. In northeastern forests recently invaded by exotic earthworms, dramatic impacts have been observed. Most notably, earthworm trophic activity dramatically reduces or eliminates the surface organic horizon or "forest floor" (Alban and Berry 1994) – an important structural feature of temperate forest soils important in nutrient cycling, regeneration and protection from soil erosion (Bormann and Likens 1979). In doing so, earthworms accelerate nutrient cycling, redistribute nutrients vertically among soil horizons and alter availability of key forest nutrients such as phosphorus and nitrogen; these effects are likely to vary depending upon many factors including forest composition, land use history, and species of invading earthworms (Bohlen et al. 2004). Some effects on herbaceous species composition have been observed (Hale et al. 2000).

Several species of invasive exotic terrestrial plants are currently impacting northeastern terrestrial ecosystems, by competing with native flora, altering habitat, and altering ecosystem dynamics such as nutrient cycling and hydrology (Mack et al. 2000). A few of the most significant invasive plants are briefly described herein. Norway maple is a hardy and prolific invader of forested habitat. It is very shade tolerant and can dominate regeneration in natural areas near suburban habitat where it has been planted as a landscaping or street tree (Webb et al. 2000). The aggressive shrub, European buckthorn, has escaped from hedgerow and other plantings to become a common species in northeastern forests. A dense understory of exotic Bush honeysuckles smother many northeastern woodlands, shading out native species and attracting bird dispersers. Likewise, the aggressive European garlic mustard invades a wide variety of open and forested habitats, displacing native wildflowers (Welk et al. 2002). Oriental bittersweet is a vine that overshadows forest edges and disturbed woodlands in southern New England and New York, smothering the vegetation beneath.

2.4.7.2 Feral Animals/Free-Ranging Pets

An additional category of "exotic species" that have a significant presence in some NETN parks are free-ranging and feral cats and dogs. While pet cats and dogs have great value to humans, the impacts of free-ranging and feral cats and dogs on natural ecosystems are only beginning to be understood. Free-ranging refers to animals which are kept as pets, but which are allowed to roam outdoors freely; feral animals are those that have escaped domesticity to live in the wild, although these animals are sometimes fed by humans. Both cats and dogs are natural predators. A growing body of literature indicates that free-ranging and feral cats are responsible for substantial mortality to small mammals and birds, and perhaps reptiles and amphibians as well (Pearre and Maass 1998, Fitzgerald and Turner 2000, Hall et al. 2000, Woods et al. 2003, Lepczyk et al. 2004). Because free-ranging cats are fed and cared for by humans, they may attain higher population densities than native predators, and thus exert abnormally high predation pressure on natural ecosystems. Moreover, cats are opportunistic predators (Coman and Brunner 1972, Barratt 1997), indicating adequate food supply at home does not prevent cats from predating native wildlife. Home-range of free-ranging cats was estimated using radio-telemetry in one study to vary up to 28 hectares, with the mean range about 8 hectares (Barratt 1997). Dogs are less effective predators than cats, but free-ranging dogs instinctually chase native mammals and other wildlife, which can stress, injure or kill those animals (Sime 1999, Miller et al. 2001). In addition, anecdotal evidence indicates that free-ranging dogs may negatively impact ground vegetation by digging and trampling; this maybe particularly true in areas near trails which are frequented by dog-owners walking their dogs off-leash. Many NETN parks are small, and several lie within densely inhabited suburban areas presumably with substantial pet populations; thus several NETN parks may be particularly at risk... Table 1.7 indicates that natural resource staff at most NETN parks recognize this issue as an existing threat. Management options for affected parks include enforcement of regulations requiring dogs to be leashed, or prohibiting dogs from sensitive areas; public education campaigns which inform the public about free-ranging pet impacts upon wildlife, and encourage keeping cats indoors; and removal of nearby colonies of feral cats. A variety of wildlife conservation organizations, including the Wildlife Society and the National Audubon Society, advocate some or all of these management strategies.

2.4.7.3 Deer Herbivory

In addition to exotic species, many northeastern ecosystems currently are impacted by an elevated population of white-tailed deer browsers. In many parts of the northeastern U.S., deer populations have reached historic high levels due a combination of habitat modification and the extirpation of natural predators (Augustine and deCalesta 2003). Natural resource staff at most NETN parks have identified deer herbivory as an existing threat; this threat is greatest at parks in the southwestern and more suburban parts of NETN, and within historic sites and parks that maintain prime deer habitat (Table 1.7)

Increased browsing pressure from these large populations can substantially impact tree regeneration, as well as understory and herbaceous species composition. White-tailed deer browsing preference has been shown to inhibit regeneration of hemlock, northern white cedar and some species of oak and birch, and is implicated in the decline of herbaceous diversity in some mixed forests (Rooney and Waller 2003). The impacts of heavy deer browsing can be assessed by monitoring forest regeneration within and outside deer exclosures; deer population sizes may also be monitored from hunting and roadkill records (Halls 1984). Moreover, the effects of deer browsing on vegetation can have significant impacts on associated taxa including birds (DeCalesta 1994, McShea and Rappole 2000)) and small mammals (McShea 2000).

2.4.7.4 Land Management/Agriculture/Silviculture

The national historic sites and parks within NETN are managed primarily to achieve cultural goals, such as maintaining historical landscapes or practices. In order to achieve this, these parks apply substantial land management to maintain open and/or early successional habitat (MIMA, MORR, ROVA, SAGA, SARA, WEFA), perpetuate agriculture within parks (MIMA, MORR, SARA), or practice silviculture within parks (MABI). These activities have significant ecological impacts due to direct habitat alteration, habitat fragmentation, and the application of herbicides, pesticides and fertilizers. In addition, silviculture alters forest structure, and composition, as well as ecological processes acting within affected forests, and silvicultural re-stocking can introduce exotic species or genotypes. While these activities will continue in order to satisfy park cultural mandates, it is important for the I&M program to consider how these activities affect the ecological integrity of natural park systems. There are many ways to practice land management, agriculture and silviculture, and ample opportunity for monitoring to support and inform adaptive management related to these land management activities.

2.4.7.5 Nearby Landuse/Roads

As discussed above under Landscape Context (section 2.4.6) NETN parks exist within a matrix of suburban and rural landuse fragmented by extensive road networks. These impacts of these stressors are considered above in that section, and also below within the Wetland and Aquatic Conceptual Models (sections 2.5 and 2.6).

2.4.7.6 Visitor Use

The northeast is among the most densely settled areas within the U.S., and NETN parks such as ACAD, APPA, MIMA, ROVA and MORR have high visitation rates (Table 1.3). Hikers can increase erosion on and around trails, trample nearby vegetation and cause soil compaction. These impacts can be particularly significant in high elevation areas, such as along APPA, and in areas where trails are poorly marked. Hikers can also disturb wildlife. Car traffic within parks can cause wildlife fatality, and reinforce the fragmentation effects associated with roads. Horse-riding is permitted within several NETN parks, and horses can contribute to trampling and erosion, and perhaps aid in the spread of invasive exotic species. Snowmobiling is permitted within ACAD, and may cause winter-time disturbance to wildlife.

2.4.7.7 Ozone

Tropospheric ozone is a damaging phytotoxin of significant concern within the northeastern U.S. (U.S. Environmental Protection Agency 1996). Ozone is formed by sunlight acting upon nitric oxides and simple hydrocarbons from industrial emissions and motor vehicles. Thus, trophospheric ozone levels vary rapidly in space and time, and are highest on sunny, still days in areas within and downwind of urban centers, industrial facilities and transportation corridors, but elevated background levels of trophospheric ozone occur throughout the northeastern U.S.. Natural resource managers have identified ozone as a threat at all NETN parks (Table 1.7); analysis by NPS Air Quality staff indicates that all but three NETN parks (MABI, SAGA and SARA) lie partially or completely within existing ozone "non-attainment" areas (Appendix F), indicating ozone pollution is a significant stressor at most NETN parks.

Ozone damages cell membranes, which may then reduce rates of photosynthesis and plant growth. However, ozone damage varies in a complex manner depending upon exposure, plant species, genotype, plant age, and plant stress, particularly water stress (Chapelka and Samulson 1998). For this reason, ozone is typically monitored both directly in air, and indirectly, as injury to indicator species (Coulston et al. 2003).

2.4.7.8 Atmospheric Deposition

Atmospheric deposition significantly impacts northeastern terrestrial ecosystems in complex ways that vary substantially across the landscape. Acidic deposition, derived from nitrogen and sulfur emissions from electric utilities, manufacturing, agriculture and other sources, is deposited in precipitation (wet deposition), directly onto vegetation immersed in clouds and fog (occult deposition), and also by direct transfer of particles and gases (dry deposition). Large scale patterns of wet acidic deposition across New England are well characterized - they are most extreme at high elevations and in the southern and western parts of this region which are closest to midwestern emission sources; deposition is slightly lower in central New England and along the Maine coast and lowest in northern and eastern New England (Driscoll et al. 2003). However, substantial additional acidity can result from dry and occult deposition, and these patterns of deposition are not well characterized. Within the NETN, coastal fog at Acadia may deposit substantial acidity (Weathers et al. 1986) which is not currently monitored by existing programs such as the National Atmospheric Deposition Program (NADP) and the Clean Air Status and Trends Network (CASTNET).

The effects of acidic deposition upon forested ecosystems are complex. Acidic deposition acidifies soil, leaching base cations necessary for plant nutrition, such as Ca^{2+}, Mg^{2+}, K^{+}, from the soil, and increasing availability of aluminum, a toxin. Deposition of nitrogen (N) compounds can further alter forested ecosystems - N is a limiting nutrient that has historically been retained within forested systems. As increased N inputs "saturate" forested ecosystems, excess N leaches from the system as nitrate and exacerbates the effects of acidification (Aber et al. 1998). The magnitude of these effects varies spatially across the landscape due to patterns of deposition, species composition, soil buffering capacity, and landuse history (Lovett et al. 2000, Aber et al. 2004). These effects also vary temporally; in particular, spring snowmelt can release substantial acidity accumulated during the winter.

The effects of these changes upon northeastern trees have been most well studied for red spruce and sugar maple. A substantial body of evidence indicates that acid deposition causes dieback of red spruce by decreasing cold tolerance due to interference with Ca^{2+} nutrition (Shortle et al. 1997, Johnson et al. 1998, DeHayes et al. 1999). Additional evidence indicates that acid deposition may contribute to sugar maple decline, particularly on marginal sites, due to base cation depletion (Long et al. 1997, Bailey et al. 1999, Horsely et al. 1999). Attempts to control emissions contributing to acidic deposition using federal regulation have yielded some decreases in sulfate deposition and prevented further increases in NO_x emissions, but recovery of affected ecosystems has lagged behind (Driscoll et al. 2003).

2.4.7.9 Climate Change

Anthropogenic global climate change is both directly and indirectly altering many key environmental parameters that control the structure, composition and function of terrestrial ecosystems. While accurate prediction of the effects of the suite of global change stressors upon terrestrial ecosystems is currently beyond our abilities, a large body of research has been assembled which yields some insight into what may occur. Easiest to predict are the direct effects of elevated atmospheric CO_2 concentrations on vegetation - elevated CO_2 has been shown to increase photosynthetic rates and tree growth, though this may be a short-term effect (Long et al. 1996, Rey and Jarvis 1998) which is likely to be limited under field conditions by nutrient limitation (Curtis and Wang 1998, Johnson et al. 1998). Enhanced CO_2 should also increase plant water use efficiency, but may reduce tissue nitrogen concentrations leaving vegetation more susceptible to herbivory and perhaps altering rates of nutrient cycling (Landolt and Pfenninger 1997, Williams et al. 1998).

It is much harder to predict the effects of changing temperature and precipitation patterns and altered disturbance regimes associated with global change. Current global change predictions suggest that the northeastern U.S. will warm over the next century, particularly during winter and at higher elevations, but it is unclear how patterns of precipitation may change (Mitchell and Johns 1997, Flato et al. 1999). In the short-term, the benefits of enhanced CO_2 may outweigh modest changes in temperature and precipitation causing increased productivity in northeastern forests (Aber et al. 2001). In the mid-term, changing environmental conditions may stress northeastern forests and exacerbate forest decline (Aber et al. 2001). Over the long-term, current predictions suggest that northern hardwood and spruce-fir forests could migrate north out of the

U.S. into Canada, and be replaced by oak-hickory and oak-pine forests (Hansen et al. 2001). Species will respond individually to climate change, causing the most severe impacts to highly mutualistic species, to poor dispersers, and to populations at the southern extent of their ranges. Current assessments of how global change may alter disturbance regimes within northeastern forested ecosystems are even more speculative, but it seems likely that hurricanes will become more frequent, that disturbances caused by invasive exotic insect pests will become more intense and widespread, and that the geographic extent of ice storms in this region may shrink (Dale et al. 2001).

2.4.7.10 Cumulative Effects

The effects of some stressors seem predictable based on current scientific understanding, while the effects of others remain quite speculative. The largest issue currently facing scientists and land managers is understanding the cumulative and interactive effects of these varied stressors upon ecosystems. For example, enhanced atmospheric CO_2 concentrations may increase plant water use efficiency, which might reduce foliar ozone exposure (Aber et al. 2001). However, increased disturbance and forest decline associated with global change is expected to increase the spread of invasive exotic species, while migratory responses of native species may be hindered by habitat fragmentation (Hansen et al. 2001). These are just a few examples - the possible interactions between this formidable suite of anthropogenic stressors are numerous, largely unstudied, and in some cases, very much unpredictable.

2.5 Wetland Resource Conceptual Model

Wetlands represent a diverse set of ecological communities that occur at the transition between terrestrial and aquatic systems. Defined based on hydrology, physiochemical environment, and biota, wetlands are some of the most productive and diverse ecosystems on earth (Keddy 2000). The physiochemical environment of a wetland is defined as the soils, chemical properties, and processes that interact with the hydrology to influence the biota. These three components form the basis for the development and functioning of wetland ecosystems.

Water is present in all wetlands for some time period but the depth and duration of flooding or *hydrology*, varies substantially among wetland types. Hydrology is the defining physical parameter that separates wetland ecosystems from terrestrial and deep water aquatic systems. Hydrology is thus the single most important factor in the establishment and maintenance of characteristic types of wetlands and wetland processes (Mitch and Gosselink 2000). Globally, freshwater species and habitats are among the most threatened in the world (Saunders et al. 2002). Freshwater withdrawals have doubled since 1960 and more than half of all freshwater runoff is used by humans (Loh et al. 1998, Saunders et al. 2002). Wetland loss in the United States has been substantial over the past 200 years. Prior to European colonization, wetlands comprised approximately 9% of the continental USA (Dahl 1990), but presently nearly 50% of the wetland area has been converted (NRC 1995). Of the remaining wetlands, only 25% are in government ownership, making the maintenance and conservation of these habitats on federal lands a high priority.

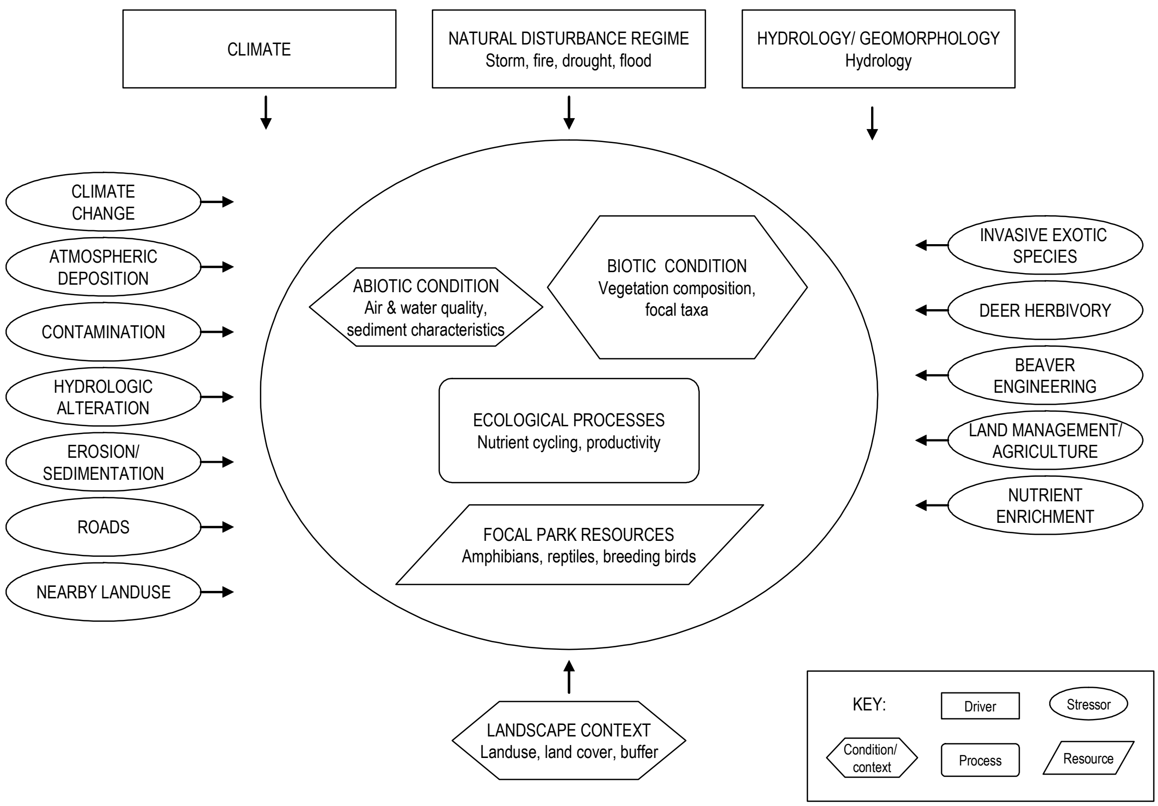
In the northeast United States depressional wetlands and seeps are a priority because of the major function they provide to amphibian breeding (Brinson and Malvarez 2002). These wetlands are most commonly altered or destroyed by urban and suburban development (Brinson and Malvarez

2002), a primary threat to NETN park natural resources. Wetland loss in NETN states has been substantial with an average loss of 38% (± 21%) of the original extent. Connecticut has suffered the most dramatic loss, with 74% of the states wetlands filled or degraded since the 1780's (Mitsch and Gosselink 2000).

In this section we present the wetland resource conceptual ecological model as a diagram (Figure 2.2) accompanied by the following narrative describing our current understanding of wetland system components and their interactions.

Figure 2.2 Conceptual Model for Wetland Systems

Forested wetland, Open/shrub wetland, Peatland, Vernal pool



2.5.1 Ecological Systems

Wetlands in NETN parks are an important component of park ecological condition and provide valuable habitat to a suite of obligate and facultative wetland flora and fauna. Wetlands are present in all NETN parks (Table 2.2 and see Appendix K) and provide valuable ecological and social services therein. Ecologically, wetlands contribute greatly to biological diversity, provide flood storage, and improve water quality, while socially they provide scenic viewsheds, educational opportunities, and contribute to our natural heritage.

Table 2.2. *Approximate extent (hectares) of NatureServe freshwater wetland ecological systems present within NETN parks. This information will be updated and improved after completion of the I&M mapping inventory of these parks. Area listed in larger boxes spanning more than one ecological type indicates that current information does not distinguish between related types. Information for APPA is not yet available.*

Ecosystem Category	NatureServe Ecological System Type	ACAD	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
Floodplain forest	Laurentian-Acadian Floodplain Forest				4					30	
	Central Appalachian Floodplain										
Softwood/hardwood swamp	Eastern Boreal Semi-Treed Bog	146									
	Laurentian-Acadian Acidic Swamp	214		4	58					3	
	North-Central Appalachian Acidic Swamp					6	9				1
Peatlands	Acadian Maritime Bog	37									
	Laurentian-Acadian Acidic Basin Fen	216			2						
	Laurentian-Acadian Alkaline Fen	68									
Wet meadows/shrub swamps	Laurentian-Acadian Wet Meadow-Shrub Swamp and Marsh	223	12	0.2	42	9	3	5	2	4	3

Wetlands in NETN parks are comprised of nine different types of wetland ecological systems (NatureServe 2003) and vernal pools. These types are summarized below, and described in greater detail within Appendix C.

- **Laurentian-Acadian Floodplain Forest**: This system encompasses north-temperate floodplains in the northeastern and north-central U.S. and adjacent Canada at the northern end of the range of silver maple. They occur along medium to large rivers where topography and process have resulted in the development of a complex of upland and wetland temperate alluvial vegetation on generally flat topography. This complex includes floodplain forests, with *Acer saccharinum* characteristic, as well as herbaceous sloughs and shrub wetlands. Most areas are underwater each spring; microtopography determines how long the various habitats are inundated. Associated trees include *Acer rubrum* and *Carpinus caroliniana*, the latter frequent but never abundant. On terraces or in more calcareous areas, *Acer saccharum* or *Quercus rubra* may be locally prominent, with *Betula alleghaniensis* and *Fraxinus* spp. *Salix nigra* is characteristic of the levees adjacent to the channel. Common shrubs include *Cornus amomum* and *Viburnum* spp. The herb layer in the forested portions often features abundant spring ephemerals, giving way to a fern-dominated understory in many areas by mid-summer. Non-forested wetlands associated with these systems include shrub-dominated and graminoid-herbaceous vegetation.

- **Central Appalachian Floodplain Forest**: This system encompasses floodplains from New England to Virginia. Mostly forested, these occur on floodplains of medium to large rivers where topography and process have resulted in the development of a relatively flat floodplain with a complex of upland and wetland temperate alluvial vegetation. This complex includes floodplain forests in which *Acer saccharinum*, *Populus deltoides*, and *Platanus occidentalis* are characteristic, as well as herbaceous sloughs and shrub wetlands. Most areas are underwater each spring; microtopography determines how long the various habitats are inundated. Depositional and erosional features may both be present depending on the particular floodplain, although there is a history of deposition in the floodplain formation.

- **Laurentian-Acadian Acidic Swamp**: These forested wetlands are found in temperate northeastern and north-central U.S., primarily in glaciated regions in the Laurentian-Acadian region. They occur on mineral soils that are nutrient-poor. There may be an organic epipedon, but the substrate is not deep peat. These basin wetlands remain saturated for all or nearly all of the growing season, and may have standing water seasonally. There may be some seepage influence, especially near the periphery. *Acer rubrum, Fraxinus* spp., *Picea rubens* (rarely *Picea mariana*), and *Abies balsamea* are the most typical trees. The herbaceous and shrub layers tend to be fairly species-poor. *Nemopanthus mucronatus* and *Osmunda* spp. are typical shrub and herb species.

- **Eastern Boreal Semi-Treed Bog**: These peatlands are found at the higher temperate and near-boreal latitudes of the northeastern and north-central United States and adjacent Canada, where climate allows the rate of peat accumulation to exceed its decomposition, resulting in ombrotrophic and acidic peatlands in which the bog surface is raised above the water table. The surface morphology of the bog may be more-or-less level, domed, or eccentric. The vegetation is dominated by low ericaceous shrubs (including *Kalmia angustifolia, Kalmia polifolia, Ledum groenlandicum*, and *Chamaedaphne calyculata*), with patches of conifers, graminoids and bryophyte lawns. Secondary bog pools may be present. While the raised portion defines these bogs, fen vegetation is usually present along the perimeter.

- **North-Central Appalachian Acidic Swamp**: These swamps are distributed through the Central Appalachians south to Virginia. They are found in basins, or on gently sloping seepage lowlands. The acidic substrate is mineral soil, often with a component of organic muck; if peat is present, it usually forms an organic epipedon over the mineral soil rather than a true peat substrate. *Tsuga canadensis* is usually present and may be dominant. It is often mixed with deciduous wetland trees such as *Acer rubrum* or *Nyssa sylvatica*. *Sphagnum* is an important component of the bryoid layer. Basin swamps tend to be more nutrient-poor and less species-rich than seepage swamps; in some settings, the two occur adjacent to each other with the basin swamp vegetation surrounded by seepage swamp vegetation on its upland periphery.

- **Acadian Maritime Bog**: These ombrotrophic acidic peatlands occur along the north Atlantic Coast from downeast Maine east into the Canadian maritimes. When these form in basins, they develop raised plateaus with undulating sedge and dwarf-shrub vegetation. *Trichophorum caespitosum* may form sedge lawns on the raised plateau. The system may also occur as "blanket bogs" over a sloping rocky substrate in extreme maritime settings; here, dwarf-shrubs and *Sphagnum* are the dominant cover. Species characteristic of this maritime setting include *Empetrum nigrum* and *Rubus chamaemorus*. Typical bog heaths such as *Kalmia angustifolia, Kalmia polifolia, Gaylussacia baccata, Ledum groenlandicum*, and *Gaylussacia dumosa* are also present. Morphological characteristics and certain coastal species distinguish these from more inland raised bogs. The distribution is primarily Canadian, and these peatlands are rare in the U.S.

- **Laurentian-Acadian Acidic Basin Fen**:This peatland system ranges over a broad geographic area across the glaciated northeast to the Great Lakes and upper Midwest. The fens have developed in open or closed, relatively shallow basins with nutrient-poor and acidic conditions. Many occur in association with larger lakes or streams. The substrate is *Sphagnum*, and vegetation typically includes areas of graminoid dominance and dwarf-shrub dominance. *Chamaedaphne calyculata* is usually present and often dominant. Scattered stunted trees may be present. These fens often develop adjacent to open water. They lack the ribbed or reticulate microtopographical patterning of the patterned fen system.

- **Laurentian-Acadian Alkaline Fen**: These fens, distributed across glaciated eastern and central North America, develop in open basins where bedrock or other substrate influence creates circumneutral to calcareous conditions. They are most abundant in areas of limestone bedrock, and widely scattered in areas where calcareous substrates are scarce. The vegetation may be graminoid-dominated, shrub-dominated, or a patchwork of the two; *Dasiphora fruticosa ssp. floribunda* is a common diagnostic shrub. The herbaceous flora is usually species-rich, and includes calciphilic graminoids and forbs. *Sphagnum* dominates the substrate; *Campylium stellatum* is an indicator bryophyte. The edge of the basin may be shallow to deep peat over a sloping substrate, where seepage waters provide nutrients.

- **Laurentian-Acadian Wet Meadow-Shrub Swamp and Marsh**: This system encompasses shrub swamps and herbaceous emergent to submergent mineral-soil wetlands of the Northeast and upper Midwest. They are often associated with lakes and ponds, but are also found along streams, where the water level does not fluctuate greatly. The size of occurrences ranges from small pockets to extensive acreages. The emergent wetlands often have a patchwork of shrub and graminoid dominance; typical species include *Alnus incana, Spiraea alba, Myrica gale, Calamagrostis canadensis*, tall *Carex* spp., and *Juncus effusus*. Trees are generally absent and, if present, are scattered. Submergent wetlands include a variety of macrophytes, often with a border of non-persistent emergent vegetation dominated by *Pontederia cordata*. The submergent vegetation zones may be severely impacted by non-native invasive aquatics including *Myriophyllum spicatum* and others.

- **Vernal Pools**: Vernal pools are temporary bodies of fresh water inhabited by many species of wildlife, some of which are totally dependent on the pools for their survival (DiMauro and Hunter 2002). Temporary freshwater pools provide critical habitats for breeding populations of amphibians and invertebrates dependent upon fishless environments for successful recruitment (Semlitsch and Bodie 1998). Periodic drying of vernal pools eliminates fish populations and breeding populations of other predators such as bullfrogs (*Rana catesbeiana* Shaw) and green frogs (*Rana clamitans* Latreille). Thus, vernal pools provide a unusual low predation environments for many amphibians. Vernal pools occur throughout North America within both closed canopy and open canopy communities. In northeastern North America, vernal pools are typically found in upland forest and floodplain depression systems that are filled by spring rains, snowmelt, or seasonally raised water tables (Brooks et al. 1998, Brooks and Hayashi 2002). Candidate systems within the Northeast Temperate Network where vernal pools may occur include the following: Laurentian-Acadian Floodplain Forest, Central Appalachian Floodplain, Acadian Lowland Spruce-Fir-Hardwood Forest, Laurentian-Acadian Northern Hardwood Forest, Laurentian-Acadian Pine-Hemlock-Hardwood Forest, and Appalachian Hemlock-Hardwood Forest.

2.5.2 Ecosystem Drivers

2.5.2.1 Climate

Climate is a key driver of wetland ecological systems. The temperate climate of NETN parks is described above in section 2.3, and the potential ecological effects of anthropogenic climate change are discussed below in section 2.5.7.

2.5.2.2 Disturbance Regimes

Natural disturbances to wetlands in NETN influence hydrology and therefore change the abiotic and biotic attributes of the wetland system. Changes to hydrology can occur naturally to wetlands through succession, beaver engineering, sediment transports, severe weather events, and ice scouring. Severe weather events are the most common source of natural disturbance for wetlands in the NETN and determine the extent and duration of floods and droughts. The direct consumption of plants by geese, muskrats, and other herbivores can be common in some wetlands and greatly alters the vegetation composition and structure (Mitch and Gosselink 2000). Known as “eat outs”, these natural disturbances convert large expanses of wetlands from emergent vegetation to open water (Middleton 1999).

2.5.2.3 Hydrology/Geomorphology

Hydroperiod (the frequency and duration of soil inundation) defines the hydrology of a specific wetland and largely determines the type of wetland that will develop in a particular setting. Wetland hydroperiod is influenced by basin morphometry, wetland size, connection of the wetland to ground–water resources, and long-term climatic conditions (Larson 1995, Lent 1997, Kirkman et al. 1999, Brooks and Hayashi 2002). Annual variation in hydroperiod is thought to be an expression of the annual variation in weather patterns, specifically precipitation (Winter 2001). Moreover, hydroperiod is the most important physical factor driving the composition and diversity of the wetland floral and faunal communities and wetland productivity (Semlitsch et al. 1996, Schneider 1999, Mitsch and Gosselink 2000, Brooks 2004). Therefore, monitoring wetland hydroperiod not only provides detailed information about wetland condition, structure, and function but also can be used as a corollary to better understand the ecological effects of changing weather patterns.

(Weyrauch and Grubb 2004) found hydroperiod to be the most important variable in predicting amphibian species richness and showed a positive relationship between hydroperiod and species richness. (Snodgrass et al. 2000)recommended that an array of small wetlands with variable hydroperiods be conserved in order to maintain biological diversity at the landscape scale. Wetlands of shorter hydroperiods and smaller size are likely to support species not found in permanent wetlands because of the absence of fish predation in ephemeral wetland (Semlitsch and Bodie 1998, Gibbs 2000, Snodgrass et al. 2000). Alterations to hydroperiod that increase flooding can reduce the extent of emergent vegetation, alter the benthic community, and decrease water clarity. Hydrologic alterations that increase the duration of water level drawdown periods reduce wetland size, limit amphibian breeding, and can increase the probability of invasion by exotic plant species.

The geomorphic setting of the wetland is important in determining wetland type and the dominant sources of water a wetland receives (Brinson et al. 1998). Wetlands of different geomorphic settings usually receive different sources of water, have different hydroperiods and therefore, different species compositions (Brinson et al. 1998, Mitsch and Gosselink 2000). Wetlands with similar geomorphic settings tend to be subjected to the same anthropogenic stressors (Brinson and Malvarez 2002). Depressional wetland hydrology is tightly correlated with groundwater levels making this wetland type subject to complete drying during periods of groundwater withdrawal. Periods of complete drying can eliminate the role of depressional wetlands in maintaining wetland faunal diversity, especially amphibians (Semlitsch and Bodie 1998).

2.5.3 Abiotic and Biotic Condition

2.5.3.1 Abiotic Condition

Soil and water chemistry vary widely among wetlands (Mitsch and Gosselink 2000). The chemistry of freshwater marshes differs substantially from the chemistry of ombrotrophic bogs, with differences related to the magnitude of nutrient inputs and the relative importance of ground water and surface water inflow . Inflowing water to freshwater wetlands tends to have higher amounts of dissolved minerals, including nutrients, compared to bogs that are fed by precipitation only. The pH of most freshwater marshes is generally circumneutral to slightly basic whereas the pH of bogs generally decreases as the organic content increases, creating a gradient of soil acidity among different wetland types (Mitsch and Gosselink 2000).

Nutrient concentrations in wetland systems are greatly influenced by flooding events, connection with groundwater, nutrient uptake by plants, and substrate or parent material (Mitsch and Gosselink 2000). Flooding in wetland systems is controlled by seasonal changes in precipitation, runoff, and evapotranspiration, and in the northeast occurs most frequently during the spring and fall when evapotranspiration is reduced.

Amphibians are very sensitive to wetland water chemistry and ion concentration is particularly important for amphibian development (Cook 1983, Hofstra and Smith 1984, Freda and Dunson 1986, Portnoy 1990, Turtle 2000). Low pH can be especially detrimental to developing amphibian embryos and Portnoy (1990) observed complete mortality of spotted salamander (*Ambystoma maculatum*) embryos in vernal pools having a pH of 4 or lower. Turtle (2000) found that de-icing salts heavily contaminate roadside wetlands and reduced spotted salamander survivorship.

2.5.3.2 Biotic Condition

Algae are an important component of wetland systems and are often a more important source of energy than vascular plants (Neill and Cornwell 1992, Peterson et al. 1993, Adamus et al. 2001). Algae are commonly grouped based on where they occur in the vertical strata. Phytoplankton are algal species suspended in the water column, metaphyton are unattached and floating, benthic algae are attached to the substratum, and epiphytic algae are attached to plants (Adamus et al. 2001). Algal production is often limited by phosphorous and nitrogen and most algal groups are sensitive to changes in the concentrations of these macronutrients (Bothwell 1989) making them potential indicators of eutrophication and nutrient enrichment.

Vascular plants, or macrophytes, are increasingly being used as indicators of wetland condition (Adamus et al. 2001). Macrophytes are commonly used to delineate wetland boundaries and to classify wetland types. Common plant species in northeast wetlands include: red maple (*Acer rubrum*), silver maple (*Acer saccharum*), green ash (*Fraxinus pennsylvanica*), buttonbush (*Cephalanthus occidentalis*), meadow-sweet (*Spiraea alba*), speckled alder (*Alnus incana*), willow (*Salix spp.*), common cattail (*Typha latifolia*), pickerelweed (*Pontederia cordata*), broad-leaved arrowhead (*Sagittaria latifolia*), and sphagnum mosses (*Sphagnum spp.*).

Wetland invertebrates are important trophic links between plants and their detritus, and animals and fish (Mitsch and Gosselink 2000). Many groups of insects serve important roles in wetland nutrient cycling by shredding plant material to increase availability to bacteria (Adamus et al. 2001). Invertebrate fauna are increasingly being used as indicators of wetland condition (Adamus et al. 2001). Some invertebrate species, such as fairy shrimp (*Eubranchipus* spp.), are also entirely dependent upon vernal pool habitat and many species act as important predators and prey in wetland ecosystems (King et al. 1996).

Amphibians and reptiles are the dominant vertebrate groups in many freshwater systems of NETN parks. Common species include the American toad (*Bufo americanus*), green frog (*Rana clamitans*), American bullfrog (*Rana catesbiena*), gray treefrog (*Hyla versicolor*), pickeral frog (*Rana palustris*), spring peeper (*Pseudacris crucifer*), eastern newt (*Notophthalmus viridescens*), painted turtle (*Chrysemys picta*), Blanding's Turtle (*Emydoidea blandingii*), and snapping turtle (*Chelydra serpentina*). Some species like, wood frog (*Rana sylvatica*), the eastern spadefoot toad (*Scaphiopus h. holbrooki*), and the four species of mole salamander (*Ambystoma* spp.) have evolved breeding strategies intolerant of fish predation and are considered vernal pool obligate breeders. The lack of fish populations is essential to the breeding success of these species. Vernal pools are a high conservation priority in the northeast due to the loss of vernal pools and general lack of regulatory protection for these ephemeral habitats.

Other dominant wetland faunal groups include mammals and birds. Beaver (*Castor canadensis*) and muskrat (*Ondatra zibethicus*) are common in NETN wetlands; both of these species can cause major changes in marsh vegetation structure and composition. Common wetland avi-fauna include least bittern (*Ixobrychus exilis*), American bittern (*Botaurus lentiginosus*), great blue heron (*Ardea herodias*), black-crowned night heron (*Nycticorax nycticorax*), wood duck (*Aix sponsa*), black duck (*Anas rubripes*), Virginia rail (*Rallus limicola*), Sora (*Porzana carolina*), marsh wren (*Cistothorus palustris*), northern waterthrush (*Seiurus noveboracensis*), and red-winged blackbird (*Agelaius phoeniceus*).

2.5.4 Ecological Processes

2.5.4.1 Nutrient Cycling

A major feature that separates wetland from terrestrial systems is the anaerobic nature of wetland soils (Morris 1991). The absence of oxygen in wetland soils slows the decomposition of organic material compared to terrestrial systems. Wetlands, because of the gradients in available oxygen, maintain the widest range of oxidation-reduction reactions of any ecosystem type (Keddy 2000).

This effectively allows wetlands to function as transformers of nutrients and metals where elements are converted among an array of chemical states (Mitsch and Gosselink 2000). Wetland nutrient cycling is dominated by the detritus food web where bacteria and invertebrates are a key component in nutrient cycling. Most nitrogen is stored in these organic sediments. Nitrogen cycling within a wetland is controlled by the temperature, pH, and the amount of available oxygen (Keddy 2000). Both nitrogen and phosphorous are limiting to wetland productivity and are often interdependent (Mitsch and Gosselink 2000).

2.5.4.2 Productivity

Wetland primary productivity estimates are high and range from 500-6000 g $m^{-2}yr^{-1}$ (Mitsch and Gosselink 2000). Productivity varies among wetland types, primarily dependent on wetland hydrology. Wetlands with flowthrough hydrology (e.g., fens) tend to have higher primary productivity than stagnant, ombrotrophic systems (e.g. bogs, (Mitsch and Gosselink 2000). Hydrology, the main pathway through which nutrients are transported into and through wetlands, greatly influences wetland productivity.

Wetlands are pulsed ecosystems where changes in water levels influence the flow of nutrients and oxygen and therefore, productivity. Wetland productivity is also related to the efficient functioning of both the grazing and detritus food chains. In bogs, where there is little or no pulsing, organic matter accumulates to form peat rather than being broken down and released into the system. Variation in productivity can be primarily attributed to summer temperatures, with a positive relationship between temperature and productivity (Gorham 1974) and genetic differences among plant species in photosynthetic efficiency (Kvet and Husak 1978).

2.5.5 Focal Park Resources

2.5.5.1 Amphibians and Reptiles

Amphibians occur in all NETN parks and are the organisms most sensitive to changes in water quality, wetland condition, and wetland landscape context. Amphibians are experiencing species extinctions and population declines globally with causes ranging from direct habitat destruction (Blaustein and Wake 1990, Fellers and Drost 1993), changing climate (Rohr and Madison 2003), disease (Blaustein et al. 1994), contaminants (Beattie and Tyler-Jones 1992), and introduced species (Hayes and Jennings 1986). The extreme sensitivity of amphibians to environmental stressors, their ubiquitous distribution in the northeast, and their importance to the public, make this group an important focal resource to be included in a long-term monitoring program.

Declines and extinctions in amphibian species are not limited to heavily developed or degraded areas. Two species-- the Northern Ducky Salamander (*Desmognathus fuscus*) and the Northern Leopard Frog (*Rana pipiens*) -- were once present in Acadia NP (Manville 1939, Coman 1987), but recent inventory work did not detect these species (Behler et al. 2004). The potential loss of two species from Acadia NP is troubling and emphasizes the need for monitoring amphibian population status, not only as an indicator of wetland condition, but as early warning of species population declines.

Most amphibians and many reptiles require aquatic habitats during some stage of their annual cycle and are therefore especially vulnerable to wetland alteration and/or contamination (Stebbins and Cohen 1995, Dodd and Cade 1998, Lannoo 1998). Amphibians and reptiles, because of their limited dispersal ability and migration patterns, are especially sensitive to the landscape matrix surrounding wetlands (Gibbs 1998a, b).

2.5.6 Landscape Context

Habitat fragmentation and buffer loss are major anthropogenic stressors to surrounding wetland habitats. Freshwater systems are affected by land-use activities occurring upstream. Land-use practices that alter land cover types to reduce native vegetation can affect freshwater systems by modifying nutrient loads, sediment accretion, water temperature, and contaminant inputs (Saunders et al. 2002).

Wetland density on the landscape is often cited as an important explanatory variable in population and community level studies of species persistence and distribution (Fahrig and Merriam 1985, Kotliar and Wiens 1990). High wetland density on the landscape may reduce the risk of local species extirpation by maintaining hydrologic regimes and minimizing costs associated with dispersal (Morris 1992, Mitsch and Gosselink 2000). Landscape orientation of wetlands, especially small isolated wetlands, is a critical determinant of obligate species population viability (Gibbs 1993, Guerry and Hunter 2002). Wetlands tend to be spatially aggregated and hydrologically linked (Brooks et al. 1998). Dispersal opportunities among wetlands are needed to maintain viable populations of organisms dependent on wetland habitats. In this context, metapopulation models may serve as a basis for understanding amphibian dispersal and colonization behavior. However, quantitative information needed for effective population modeling is lacking (Brooks et al. 1998).

Wetland patch size has also been shown to be an important metric in determining wetland condition and many studies have shown that patch size is fundamentally important in maintaining biodiversity (Fahrig and Merriam 1985, Robinson et al. 1992).

Amphibians and reptiles are especially sensitive to the matrix of habitats surrounding a wetland because they spend the majority of their lives foraging, resting, and hibernating in the surrounding terrestrial habitat (Semlitsch 1998). Upland habitats immediately surrounding wetlands serve as important dispersal corridors and are also used as foraging and aestivation areas for many amphibian species (Semlitsch 1998). (Weyrauch and Grubb 2004) found woodlot characteristics surrounding a wetland to be the most important variables predicting caudate species richness. Semlitsch (1998) monitored terrestrial migrations for six Ambystomid salamander species and concluded buffer areas 164 m from wetland edges were needed to encompass 95% of population forays. Total forested area around the wetland also seems to be an important landscape component in the maintenance of wetland fauna. Guerry and Hunter (2002) found that wood frogs, green frogs, eastern newts, spotted salamanders, and salamanders of the blue-spotted/Jefferson's complex (*Ambystoma laterale*/*A. jeffersonianum*) were more likely to occupy ponds in more forested areas than areas with low forest cover.

Roads are among the most widespread forms of habitat modification on the landscape and can have profound effects on wetland communities (Trombulack and Frissell 2000, DiMauro and Hunter Jr 2002, Gibbs and Shriver 2002, Forman et al. 2003). Road construction has been implicated in the significant loss of wetland biodiversity at both local and regional scales for birds, herptiles, and vascular plants (Findley and Houlahan 1997). Fragmentation resulting from road construction and the associated traffic intensity can act as a barrier to amphibian movement and reduce amphibian abundance (Fahrig et al. 1995, Gibbs 1998a, deMaynadier and Hunter 2000). The combined effects of ionic inputs, edge effects (deMaynadier and Hunter 1998), and adult mortality make roads an important landscape component to monitor when estimating wetland condition. (Findley and Bourdages 2000) documented lag times associated with the negative response of species richness to road construction and suggested that the affects of road construction may not be detectable for decades.

2.5.7 Stressors

In this section, we summarize knowledge about the effects of key stressors upon NETN wetland systems. The park-based conceptual ecological models within Appendix K reveal important stressors acting upon specific parks.

2.5.7.1 Atmospheric Deposition

Anthropogenic atmospheric deposition can dramatically affect water quality in wetland systems. Acidic deposition, in the form of nitrogen and sulfur oxides, can alter wetland structure and function (Morris 1992). Another significant component of anthropogenic air pollution is mercury. Although mercury is a naturally occurring element, studies show that human activities have more than tripled its concentration in the environment, which can cause negative impacts in wetland systems, such as direct toxicity and reduced fecundity of secondary consumers.

The deposition of nitrogen compounds is the major stressor to wetland systems caused by atmospheric deposition. Bodies of water receiving elevated amounts of nitrogen compounds often show signs of water quality degradation. Atmospheric deposition of nitrogen occurs as wet (in precipitation) and dry (sorption of nitrogen gasses by wet surfaces) deposition and through the capture of fog or cloud droplets by vegetation (occult, (Morris 1992). Atmospheric deposition of nitrogen compounds can lead to eutrophication, or harmful increases in the growth of algae within wetland systems. Nitrogen pollution and the resulting eutrophication of wetlands, alters species composition of both flora and fauna and in some cases, nitrogen pollution can contribute to the acidification of water bodies.

Acidification is also common in water bodies in the eastern United States where weather patterns deposit acids derived from air pollutants generated in the Midwest and points further west. The effects of acid deposition depend greatly upon characteristics of the water body in which they are deposited. Aquatic organisms in acidified waters often suffer from calcium deficiency, which weakens bones and exoskeletons and can cause eggs to be weak or brittle. It also affects the permeability of fish membranes and particularly, the ability of gills to take in oxygen from water. Increasing amounts of acid in a wetland change the mobility of certain trace metals like aluminum, cadmium, manganese, iron, arsenic, and mercury. Acid deposition has lowered the pH, decreased the acid-neutralizing capacity (ANC), and increased the aluminum concentrations causing a decline in aquatic species diversity and abundance in the northeast (Driscoll et al. 2001a). Many amphibian species are susceptible to increasing pH, especially those breeding in temporary wetlands or vernal pools. Permanent wetlands may have a natural buffer capacity to neutralize acidification but ephemeral wetlands are created by snow melt or spring runoff which tends to concentrate acid and lower pH. Algae are affected by acidification as a result of direct toxicity and changes in competition with organisms less sensitive to rising pH (Adamus et al. 2001). Either extreme of acidity can diminish species richness of algal communities.

2.5.7.2 Hydrologic Alterations/Beaver Engineering

Beaver engineering is one of the most pervasive hydrologic alterations to NETN park wetlands. Water diversions of any kind can be viewed as potential agents of both positive and negative change to wetlands. Beaver can affect almost any wetland type but are especially common along streams and ponds where they build dams. Dam construction typically kills all woody vegetation, reduces the water velocity, and drastically changes plant species composition and structure (Thompson and Sorenson 2000). Beaver alteration of wetlands occurs in decadal cycles with an initial period of flooding after dam creation and impoundment followed by abandonment after the beaver deplete the food source. Thus, beavers both destroy through flooding unusual vegetation of bogs and fens, for example, but conversely create many highly productive wetlands along streams formerly dominated by upland vegetation.

2.5.7.3 Climate Change

A growing body of evidence indicates that human activities have accelerated the concentration of greenhouse gases in the atmosphere (IPCC 2002). Atmospheric models predict the average surface temperature to rise from 1.4 to 5.8ºC by 2100 (IPCC 2002). The climate of the northeastern United Sates is projected to become warmer and perhaps wetter over the next 100 yrs (New England Regional Assessment Group 2001), changes that will likely affect the structure, function, and distribution of wetlands. Both annual and seasonal minimum temperatures are predicted to increase at a greater rate than maximum temperatures (Brooks 2004). These projected increases in temperature would also increase the rate of evapotranspiration which in turn would alter wetland hydrology. Hydrologic alterations that reduced the flooding period would have the most negative impacts on ephemeral wetland or vernal pools (Brooks 2004). Changes in wetland water temperature due to rapidly changing climate are also predicted to alter the sex ratios of turtle populations because of their temperature dependent sex determination (Root and Schneider 2002). Wetland herpetofauna may be especially sensitive to changing climate caused by the synergistic effects of habitat fragmentation and the increased need for dispersal caused by a reduction in habitat quality. Increases in the rate of temperature change to wetland habits may force many individuals to disperse more frequently. As landscape matrices have become more hostile to dispersing wetland herptiles the increase dispersal may reduce populations and further bias sex ratios (Gibbs and Shriver 2002, Steen and Gibbs 2004).

Increases in temperature have already been shown to change the breeding and dispersal phenology of many species (Schneider and Root 2002). Climate change is anticipated to have a pronounced effect on freshwater ecosystems, especially those in northern latitudes (IPCC 2002). The combined effects of changes in temperature and precipitation are likely to severely alter wetland hydrology and water quality, thus jeopardizing the flora and fauna dependent on these systems. In the northeast, several frogs have advanced their first calling dates by 10-13 days since the early 1900's (Gibbs and Breisch 2001). Because amphibians are especially sensitive to temperature they can be valuable indicators of the biotic response to climate change in wetland systems.

2.5.7.4 Contamination

Within this ecological model, contamination is defined as the increase in concentration, availability, and/or toxicity of metals and synthetic substances (Adamus et al. 2001). Wetland contamination is typically associated with runoff from agricultural areas, residential and urban areas, waste water treatment facilities, and atmospheric deposition.

Heavy Metals-Heavy metals such as mercury, lead, zinc, and cadmium can be directly toxic to wetland fauna (Adamus et al. 2001). Mercury is especially problematic in the northeast where deposition is high. When mercury becomes deposited within a water body, microorganisms can transform it into a very toxic substance known as *methyl mercury*. Methyl mercury can accumulate in the tissues of fish to concentrations much higher than in the surrounding water. *Methyl mercury* tends to remain dissolved in water and does not travel very far in the atmosphere.

Combustion Emissions-Dioxins and furans are families of chemicals that are present in *combustion emissions* and are known to be highly toxic to wildlife. The most toxic dioxin compound is 2,3,7,8-tetrachlorodibenzo-p-dioxin or TCDD. In animal populations, TCDD has been shown to disrupt the endocrine system, weaken immune systems, and cause reproductive damage to wildlife populations. Similarly, the most toxic furan is a compound known as 2,3,7,8-tetrachlorodibenzofuran or TCDF. In animals, furans can cause serious damage to the stomach, liver, kidneys, and immune system. Both families of compounds are persistent in the environment and can concentrate in the tissue of fish and other animals.

Polycyclic aromatic hydrocarbons (PAHs) are a complex mix of compounds that occur in soot and exhaust from automobiles and the incineration of many different materials.

Polychlorinated biphenyls (PCBs) are extremely stable and can concentrate in the tissues of aquatic animals. Concentrations of PCBs in the tissue of some animals can reach literally hundreds of thousands of times greater than the surrounding water. PCBs can cause bronchitis, irritation of the gastrointestinal tract, nervous system impairment, fertility problems, and changes in liver function. They have been shown to cause cancer in lab animals, and are a suspected human carcinogen.

2.5.7.5 Invasive Species

Invasion of native habitats by nonindigenous species or by native species whose densities are becoming unnaturally inflated (e.g., white-tailed deer) is presently recognized as second only to direct habitat loss and fragmentation as a threat to biodiversity. Pimentel et al. (2001) estimated that invasive species cost the United States $138 billion annually making the reduction of these species a shared priority of many agencies and organizations in the United States (National Invasive Species Council 2001). Once viable populations of invasive plants become established in novel habitats, they inflict a suite of ecological damage to native species including loss of habitat, loss of biodiversity, decreased nutrition for herbivores, competitive dominance, overgrowth, struggling, and shading, resource depletion, alteration of biomass, energy cycling, productivity, and nutrient cycling (Dukes and Mooney 1999). Invasive plant species can also affect hydrologic function and balance, making water scarce for native species (Enright 2000).

Wetland invasive plant species in NETN parks presently include, but are not limited to purple loosestrife (*Lythrum salicaria*), Japanese knotweed (*Polygonum cuspidatum*), water chestnut (*Trapa natans*), flowering rush (*Butomus umbellatus*), yellow iris (*Iris pseudacorus*) and phragmites (*Phragmites australis*). These species have been detected in most parks and cause a substantial management effort to control and reduce wetland condition. Invasive plants significantly alter species composition and diversity and often form monotypic stands.

2.5.7.6 Nutrient Enrichment

Sources of nutrients, especially nitrogen and phosphorous, enter wetlands via surface water, groundwater, and the atmosphere (Brinson and Malvarez 2002) and can dramatically change the composition of both the floral and faunal communities (Bedford et al. 1999). Nutrient enrichment also increases the risk of invasive species establishment in many wetlands, a primary threat to NETN wetland and terrestrial resources. Increases in nitrogen and phosphorous in wetlands causes eutrophication, often at concentrations that exceed natural levels. The dominant source of nutrient inputs into wetland systems comes from agricultural and residential runoff. The most obvious response of wetland systems to nutrient enrichment are harmful algal blooms where algal biomass increases rapidly (Humphrey and Stevenson 1992). Eutrophication can also lead to simplification of algal communities expressed by a decrease in species richness, diversity, and evenness (Steinman and McIntire 1990). Changes in nutrient concentrations can alter macroinvertebrate populations which in turn can change the trophic dynamics between those that consume algae and those that consume vascular plants (Adamus et al. 2001).

Excessive nutrients can affect the wetland plant communities by: 1) shifting species composition from dominance by species that uptake nutrients slowly to those that exploit rapid pulses of nutrients, 2) triggering algal blooms that can shade out submersed herbaceous plants, and 3) causing dead plant material to accumulate faster than it can decompose (Adamus et al. 2001). Wetlands exposed to long-term nutrient enrichment tend to have lower plant species richness than reference wetlands. Bogs and nutrient poor wetlands are most sensitive to the negative effects of nutrient enrichment.

2.5.7.7 Soil Erosion/Sedimentation

Sedimentation is a naturally occurring process in wetland systems, but accelerated rates can have negative effects on wetland condition. Sedimentation is regarded as one of the major threats to fresh-water aquatic systems, primarily due to the effects of burial (Richter et al. 1997). Increased rates of sedimentation can affect wetlands by adding sediment-born pollutants, burial of vegetation and seed banks (Neely and Baker 1989), and change the water depth and hydroperiod. Burial can smother aquatic invertebrates and fish eggs, and reduce oxygen availability by stimulating plant growth through nutrient addition (Keddy 2000).

2.6 Aquatic Resource Conceptual Model

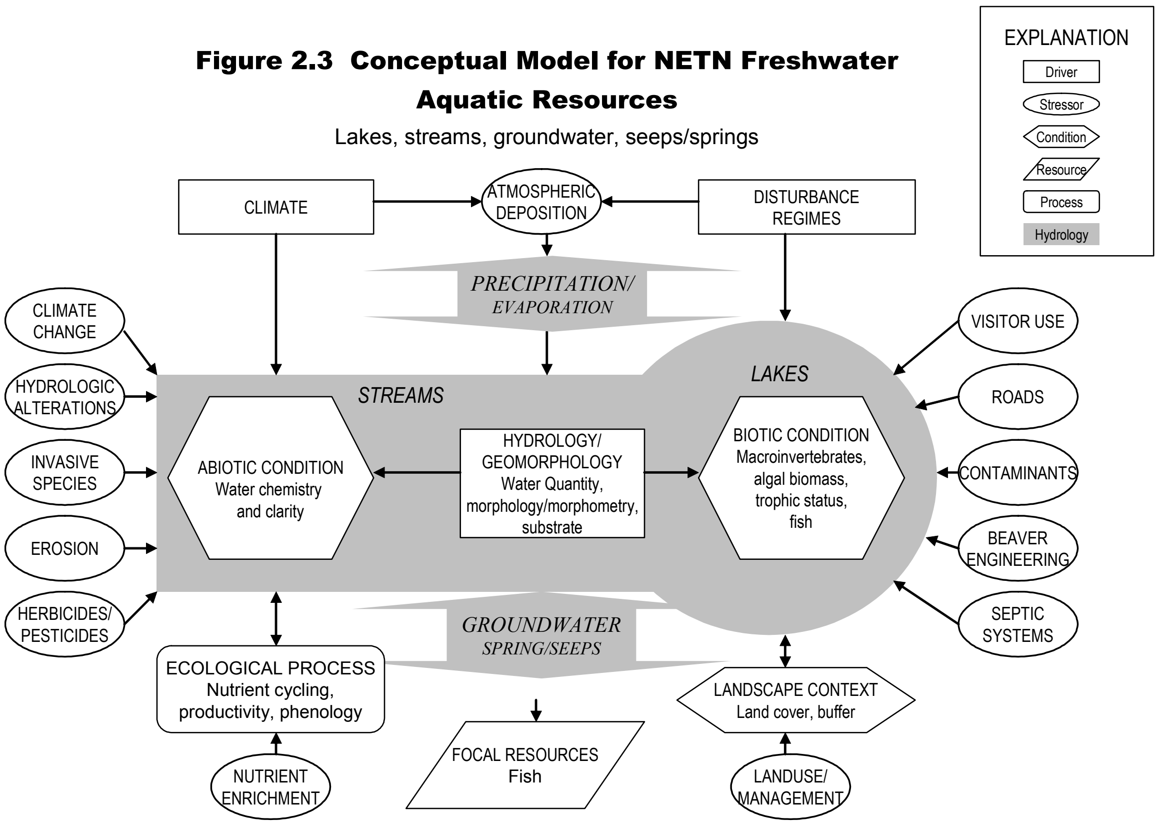
In this section we present the aquatic resource conceptual ecological model as a diagram (Figure 2.3) accompanied by the following narrative describing our current understanding of aquatic system components and their interactions.

2.6.1 Ecological Systems

Freshwater aquatic resources within NETN parks consist of lakes, ponds, streams, groundwater, and springs/seeps. These resources resulted from the activity of glacial ice sheets during the past 2.5 million years. Ice sheets deepened valleys, and transported and deposited vast quantities of sediment upon scoured bedrock as glacial drift (Randall 2001). Currently, the topographic landscape varies from rolling to mountainous upon mostly acidic bedrock and glacial till. The extent of aquatic ecological systems within NETN parks is shown in the park-based ecological models found in Appendix K.

Figure 2.3 Conceptual Model for NETN Freshwater Aquatic Resources

Lakes, streams, groundwater, seeps/springs



2.6.1.2 Lakes and Ponds

Lakes and ponds are found where the water table is at or above land surface, and are generally areas of ground-water discharge. The majority of the lake basins in the northeast U.S. were caused by unequal thickness of drift deposited in preglacial valleys; the thicker masses created dams. Thousands of such basins held lakes when the ice vanished and have become swamps or meadows (Fenneman 1938).

Nine NETN parks contain ponds smaller than 15 acres, many of which are man-made impoundments that pre-date the establishment of the parks. ACAD is the only park in which numerous lakes greater than 15 acres are a dominant part of the landscape. Lakes and ponds within NETN parks vary in type, size and trophic status (Appendix K).

2.6.1.3 Streams and Rivers

Streams and rivers within NETN parks vary from first order headwater streams to tidal rivers. Drainage patterns of northeastern streams were altered by the last glaciation. As drift was deposited in varying thicknesses, dams were created and channels blocked. Streams followed a new course based on the slope of the drift surface. After a stream cut through the drift, it often crossed ridges or ledges of hard rock and developed falls and rapids, eventually carving gorges disproportionate to the changes in relief (Fenneman 1938). Several of the parks border large rivers such as the Hudson River and the Connecticut River, and are occasionally impacted by these larger river systems during times of high water.

Information about groundwater resources and the properties and extent of aquifers making up this resource varies greatly in the northeast. The stratified drift deposited by glaciers includes a nonsorted, nonstratified mixture of grain sizes from clay and silt to large boulders. These sand and gravel deposits comprise the most productive aquifers in the northeast. These aquifers vary greatly in grain size, water-transmitting properties, and saturated thickness of the stratified drift (Randall 2001). Groundwater is also influenced by the type of bedrock underlying the stratified drift. The igneous and metamorphic bedrock that underlies much of the northeast has a hydraulic conductivity that is much lower than that of stratified drift (Randall et al. 1988). Ground-water/surface-water interactions occur in both directions and occur throughout the parks.

Springs occur where the water table intercepts the ground surface and discharge is sufficient to flow most of the time. If no flow is evident, the resulting wet areas are called seeps. Discharge of the spring is determined by the permeability and recharge of the aquifer, and thus can indicate the location and extent of an aquifer. Springs can be found at the toe of hillslopes, along depressions such as stream channels, and where the ground surface intercepts an aquifer covered by an aquiclude – a geologic barrier to groundwater flow (Brooks et al. 1991). NETN parks vary in the presence and quantity of springs and seeps.

2.6.2 Ecosystem Drivers

2.6.2.1 Climate

Climate is one of the main drivers affecting ecological properties and processes in aquatic ecosystems. The temperate climate of the northeastern U.S. is described above in section 2.3; briefly, it is characterized by changeable weather, wide ranges in diurnal and annual temperatures, distinct seasonal trends, and precipitation distributed evenly throughout the year.

2.6.2.2 Disturbance Regimes

Disturbance regimes are another major driver affecting aquatic ecosystems. Floods and droughts are the primary disturbances that affect aquatic ecosystems in NETN parks. Floods can occur during any season in the northeast, but are most widespread in the spring when large frontal systems bring steady rain which falls on frozen or saturated ground. In the summer and fall, thunderstorms and hurricanes can cause local flooding (Maloney and Bartlett 1991). Floods are natural recurring events that can cause major morphological shifts in river systems, and cause widespread erosion and sedimentation.

Droughts are more difficult to define and quantify than floods, but are also natural recurring events in the northeast. Hydrologic drought can be defined as reduced streamflows, declining ground-water levels and/or reductions in lake or reservoir levels (American Meteorological Society 1997). They can be widespread across the entire northeast, or affect only parts of the region. Droughts affect all aspects of water quantity and water quality, and can result in water use conflicts.

Long-term streamflow records show both floods and droughts and thus reflect the natural range of variability in aquatic ecosystems. Short-term records may be skewed depending upon the period of record.

2.6.2.3 Hydrology/Geomorphology

Aspects of the hydrology/geomorphology which characterize NETN parks also drive the ecological properties and processes operating in the park aquatic systems, and are described above under ecological systems (section 2.6.1).

2.6.3 Abiotic and Biotic Condition

Understanding and tracking abiotic and biotic condition is an integral part of the Inventory and Monitoring program and is directly addressed in two of the program goals. The condition of the ecosystem relates to the status of the aquatic habitat and the condition of individual species. The ecological condition of freshwater resources includes abiotic attributes such as water chemistry as well as biotic attributes such as trophic status, species composition of selected taxa, and microorganisms.

Water chemistry is critical for interpreting the biotic condition and status of ecological processes of a resource. Measures such as water temperature, dissolved oxygen and pH define the habitat in which various flora and fauna can survive. Water chemistry affects the trophic status of an ecosystem, the metabolism of aquatic species and the bioavailability of contaminants.

Vital signs that reflect biotic condition, such as composition and abundance of fish, macroinvertebrates and zooplankton, are highly relevant indicators of ecological condition that integrate the state of physical, chemical, and biological attributes of the environment. Fish communities integrate their physical, chemical, and biological environment over multiple years while macroinvertebrates do so over a single year. Zooplankton community composition and abundance is indicative of the trophic status of lakes, and reflects primary and secondary production (Porter 1977).

2.6.4 Ecological Processes

2.6.4.1 Nutrient Cycling/Productivity

Nutrient cycling, or the movement of nutrients through the water, plants, animals and sediments of freshwater ecosystems, is linked to the productivity and function of these ecosystems. The trophic status of a waterbody is also a measure of its productivity, or the rate at which organic matter is produced. The invertebrates, algae, bryophytes, vascular plants, and bacteria of freshwater systems, which are responsible for much of the work of nutrient cycling, are adapted to the specific sediment and organic matter conditions of their environment and are thus sensitive to changes in the type, size, or frequency of sediment inputs. Understanding nutrient cycling and productivity in NETN aquatic systems may provide links between ecosystem condition, ecosystem function, and stressors such as nonpoint source pollution and land use.

2.6.4.2 Phenology

Phenology, or the response of living organisms to seasonal and climactic changes in the environment, is a process that helps define the condition of the ecosystem. The combined effects of climate change and other stressors have the potential to substantially alter hydrological and biogeochemical processes, and thus, the floral and faunal communities of freshwater ecosystems of the New England/Mid Atlantic region (Moore et al. 1997). A century of data on lake ice-out dates within the northeastern U.S. shows an advance in spring ice-melt (Hodgkins et al. 2002). Similarly, a shorter record shows an advance in the timing of spring peak river flow (Hodgkins et al. 2003). These trends could affect the ecological integrity of lakes and streams by causing lower oxygen levels, eutrophication, and/or shifts in floral and faunal communities. Further research is needed to better understand relations between documented trends in freshwater systems, and the ecological integrity of these systems.

2.6.5 Focal Park Resources

Fish, discussed above as a component of biotic condition are also a focal park resource; they have broad appeal to the public and thus receive attention from NPS. The use of fish as Vital Signs is discussed above in section 2.6.3.

2.6.6 Landscape Context

The relationship between freshwater aquatic ecosystems and the surrounding landscape contributes to the condition of these ecosystems. The dimensions of a river channel reflect the interplay between the ability of water to erode the land surface and the ability of the land surface to resist erosion. Landuses such as farming, forestry, development, and water management can all affect the magnitude and frequency of streamflow and thus a river's ability to erode the land. When streams are constrained from meandering by urban alterations, hydraulic instability can cause increased deposition, erosion, slumping, over-widening or the abandonment of existing channels for new ones (Dunne and Leopold 1978). As waterbody buffers expand or contract, sources and amounts of nonpoint source pollution and runoff to the waterbody can also change. Barriers between waterbodies, such as impoundments, can inhibit the movement of species and thus affect the floral and faunal composition of a waterbody. Landscape context is linked to and reflects changing landuse, which is further discussed in the section below regarding stressors.

2.6.7 Stressors

Stressors to freshwater ecosystems in NETN parks include physical, chemical, or biological perturbations acting both inside and outside park boundaries. Many parks are not self-contained watersheds, but are at lower points in a watershed, and can be greatly influenced by alterations to the rivers, streams, or lakes that occur upstream from the parks. Furthermore, some areas that are now protected within parks were substantially altered prior to protection as a national park unit. Thus threats to freshwater aquatic resources in NETN parks cannot be evaluated without examining current and historic landuse in the region. As the landscape of the region has been transformed from agricultural to urban over the past 150 years, the increased use of automobiles and shifts in predominant industry from paper and textile mills to high-tech industry have had substantial impacts on the region's freshwater ecosystems. Key stressors currently acting on freshwater resources within NETN parks include climate change, atmospheric deposition, contaminants, nutrient enrichment, hydrologic alterations, erosion, herbicides and pesticides from both agricultural and residential use, roads, landuse and land management, visitor use, invasive exotic species, and beaver engineering. Important stressors affecting aquatic systems in specific parks are shown by the park-based conceptual ecological models within Appendix K.

2.6.7.1 Climate Change

Climate change has the potential to affect the abiotic and biotic condition of freshwater resources across the region. Several geophysical and biological studies indicate that spring is coming earlier in New England. The annual date of the last hard spring freeze became significantly earlier from 1961 to 1990 (Cooter and Leduc 1995) and lilac bloom dates at 4 stations became significantly earlier from 1959 to 1993 (Schwartz and Reiter 2000). The impacts of climate change on hydrology in the northeast are just beginning to be understood. Much of the significant change toward earlier lake ice-out dates in New England since the 1800's occurred from 1968 to 2000 (Hodgkins et al. 2003). All of 11 studied rivers in New England had significantly earlier winter/spring high flows from earlier snowmelt, with most of the change occurring in the last 30 years (Hodgkins et al. 2003). Furthermore, snow density on or near March 1 has significantly increased in coastal Maine over the last 60 years, indicating earlier spring melting (Dudley and Hodgkins 2002).

2.6.7.2 Atmospheric Deposition

Atmospheric deposition is the largest source of nitrogen to streams in the northeast. Measures of atmospheric deposition are critical for understanding water chemistry and stress (Likens and Bormann 1974). Fifty percent of total nitrogen entering New England rivers and streams in 1992-1993 was estimated to come from atmospheric deposition originating both inside and outside the region (Moore et al. 2004) Atmospheric deposition is particularly problematic in NETN parks for the surface water bodies with low acid neutralizing capacity (ANC). This parameter is a key indicator of recovery, determining the capacity of lakes and streams to buffer acidic inputs and prevent further acidification (U.S. Environmental Protection Agency 2004). The relationship between atmospheric pollution and the acid base status of surface waters is complex and nonlinear. The complexities of ecosystem response are related to confounding factors such as climate change affecting water chemistry, and the natural organic acidity of surface waters (U.S. Environmental Protection Agency 2004). Long term monitoring of atmospheric deposition as well as the water chemistry of freshwater ecosystems are critical to improving understanding of this relationship.

2.6.7.3 Nutrient Enrichment/Septic Systems

Nutrients are necessary for productive aquatic ecosystems, but in high concentrations, they can adversely affect aquatic life through excessive plant growth in streams, lakes, and coastal waters, leading to depleted dissolved oxygen, and fish kills. Nutrient concentrations in water generally are related to land use in the upstream watershed or the area overlying a ground-water aquifer (Mueller and Helsel 1996).

Total nitrogen loadings from rivers to coastal estuaries increased from 1900-1994 as a result of increasing use of nitrogen-based fertilizers, the increase in wastewater from municipal and industrial sewage, increased use of de-icing salts on roads, and increased atmospheric deposition of nitrogen. Nitrogen is released into the atmosphere from numerous sources, including fossil fuel combustion, agricultural fertilizers, and animal manure. Large amounts of municipal and industrial sewage were released directly to surface waters in the U.S. as late as the mid-1960s (U.S. Department of the Interior 1968). Aquatic concentrations of chloride, and nitrate, increased during the 20th century due to municipal and industrial wastewater discharges (Jaworski and Hetling 1996). Specific conductance and dissolved chloride concentrations increased in rivers in New England over this same period (Bell 1993, Kulp and Bohr 1993, Strause 1993, Toppin 1993, Trench 1996) likely due to the increased use of de-icing salts on roads. The passage of the Federal Water Pollution Control Act in 1972 resulted in significant improvements in wastewater treatment throughout New England. Although wastewater practices are much improved, wastewater discharges and septic system effluent can still affect water temperature and increase nutrient concentrations such as nitrogen in aquatic ecosystems.

Total phosphorus in northeast waters increased until the 1960s for many of the reasons listed above for total nitrogen, but has decreased since then because of a ban on phosphate-containing detergents (Roman et al. 2000). Water quality of three northeast rivers over the last century showed decreasing concentrations of sulfate and total phosphorus; but increasing concentrations of nitrate and chloride (Robinson et al. 2003).

2.6.7.4 Contaminants

Contaminants, including trace metals such as copper, lead, mercury, zinc, cadmium, and nickel; organic chemicals such as PCBs; polynuclear aromatic hydrocarbons (PAHs); and pesticides all have been found to adversely affect the quality of surface water and sediments in the northeastern U.S. (Maine Department of Environmental Protection, written communication, 1992). Contaminants accumulate in sediments, are consumed by bottom-feeding organisms, and then work their way up the food chain. Contaminants inhibit the growth, reproduction, and immune systems of aquatic organisms.

Anthropogenic sources of contaminants include industrial effluent, municipal wastewater, runoff from agricultural, urban and forested areas, and atmospheric deposition. Human activity speeds the rate at which naturally occurring metals leach into the environment. Concentrations of lead, mercury and zinc within stream-bottom sediments were positively correlated with urban land use in the Hudson Connecticut, Housatonic and Thames River Basins from 1992-1994 (Breault and Harris 1997, Wall et al. 1998). PCBs were used in electrical equipment until the 1970s and now persist in stream bottom sediments and biota. PAHs, released into the atmosphere by the incomplete combustion of wood, coal, petroleum products, were also found in stream bottom sediments in the Hudson River Basin, and were found to be correlated with the location of current or historic point sources (Wall et al. 1998).

2.6.7.5 Roads

As noted above in section 2.6.7.3 specific conductance and dissolved chloride concentrations have increased in rivers in New England over the 20th century (Bell 1993, Kulp and Bohr 1993, Strause 1993, Toppin 1993, Trench 1996). This is likely due to the increased use of de-icing salts on roads. Contamination of aquatic systems by road runoff and de-icing chemicals, such as rock salt and magnesium chloride, can substantially impair water quality and affect a variety of organisms.

2.6.7.6 Herbicides/pesticides

Pesticides and herbicides can enter surface water bodies through overland runoff or enter groundwater through infiltration. Concentrations and types of pesticides detected in New England streams depended upon landuse (Garabedian et al. 1998). Diazinon was most often detected at the urban sites while atrazine, metolachlor, and simazine were most frequently detected at sites draining agricultural land. Atrazine was detected at 88 percent of the agricultural sites, was frequently detected in combination with other pesticides, and was the most commonly detected pesticide overall. The high percentage of insecticides detected in urban basins reflects the use of these products on lawns. While wide spectrum pesticides such as DDT have been banned in the U.S., contemporary insecticides are soluble in water and can be toxic to fish. Herbicides, while less toxic to fish, can kill aquatic plants (Welsch 1992). Pesticides degrade slowly, accumulate over time, and can be detected in fish tissue even when the concentrations are too low to be detected in stream bottom sediments.

2.6.7.5 Hydrologic Alterations

Hydrologic alterations have many causes, including increases in impervious surface area associated with development; installation of culverts; water withdrawals and discharges; the installation of water storage and release from impoundments; and straightening and/or confining a channel within an urban area. These alterations can directly affect the aquatic flow regime, and water quality. Alterations can also affect geomorphology over the long term by dampening peak flows, changing patterns of aggradation and degradation, constricting a meandering channel, and causing local scour. Hydrologic alterations such as impoundments can restrict the movement of aquatic organisms.

2.6.7.5 Erosion

Although soil erosion is a natural aquatic process, human activities can accelerate erosion to the point where it is harmful to ecosystems. Excessive suspended sediments can block sunlight and impair photosynthesis; reduce visibility and the ability of fish and other organisms to feed; raise water temperatures and reduce dissolved oxygen; clog and damage filter feeders and fish gills. Human activities which accelerate erosion include the creation of impervious areas which increase the volume and speed of stormwater runoff and erode stream banks. Construction and forestry projects that leave the soil exposed can also accelerate erosion.

2.6.7.5 Beaver Engineering

Beavers can also cause hydrologic alterations in aquatic ecosystems. They create wetlands and marshy areas that provide habitat for hundreds of species by building dams and engineering wetlands. The near-elimination of beavers by the beginning of the 20th century led to a drying of wetlands and an expansion of meadows and forests to the detriment of marshy species. Beaver ponds and dams function as water filters that capture silt and pollutants, and result in improved water quality downstream. Despite beavers' reputation for causing flooding, their marshes help buffer adjacent landscapes against the effects of flash floods. Their network of channels, dams, and sloughs slows and holds water in the landscape longer, insulates areas from drought, and recharges underground aquifers. (Wilkinson, T., National Parks Conservation Association, written communication, 2004). Despite the many positive effects of beaver engineering, beavers create challenges for park managers when they occur at an excessive level. Beavers topple trees, flood roads, crops, and woodlands, create impoundments, flood riparian areas, and alter riparian vegetation.

2.6.7.6 Invasive Exotic Species

The presence and persistence of invasive exotic flora and fauna is a serious issue at all NETN parks. Invasive exotic species can displace native species in wetlands and riparian areas. Invasive plants contribute to the channeling (narrowing and deepening) of streams and the eutrophication and depletion of dissolved oxygen of lakes and ponds. Invasive exotic species can also profoundly affect visitor experience, by changing the quality of water used for swimming, boating, fishing, and drinking. The most prolific invasive exotic flora within NETN freshwater aquatic habitats are common reed (*Phragmites australis*), purple loosestrife (*Lythrum salicaria*), and curly pondweed (*Potamogeton crispus*). Bass and bluegill are the primary invasive exotic fauna present in NETN systems (Mather et al. 2002); these species have the potential to displace native fish communities through habitat disruption, competition for resources, and/or predation. Other exotic invasive exotic species such as zebra mussels have the potential to become management issues if introduced into NETN parks.

2.6.7.7 Visitor Use

Visitor use could be one of the most important stressors acting within boundaries of NETN parks. The NPS aims to preserve unimpaired the natural and cultural resources and values of the national park system for the enjoyment, education, and inspiration of this and future generations as a part of its mission. It is a complex task to balance the NPS mission of preserving resources unimpaired, while also having the public enjoy, and be educated and inspired by those resources. Stressors to freshwater aquatic resources related to visitor use include the extraction of natural resources (such as fish), erosion stemming from multiple uses, road runoff and contamination stemming from the many roads that allow visitor access within the parks, and the introduction of invasive species carried in by visitors. While little research has been done relating visitor use to the condition of the aquatic resources, the potential for this use to cause stress to natural ecosystems is great, especially when compounded with other stressors such as climate change and invasive exotic species.

2.7 Intertidal Resource Conceptual Model

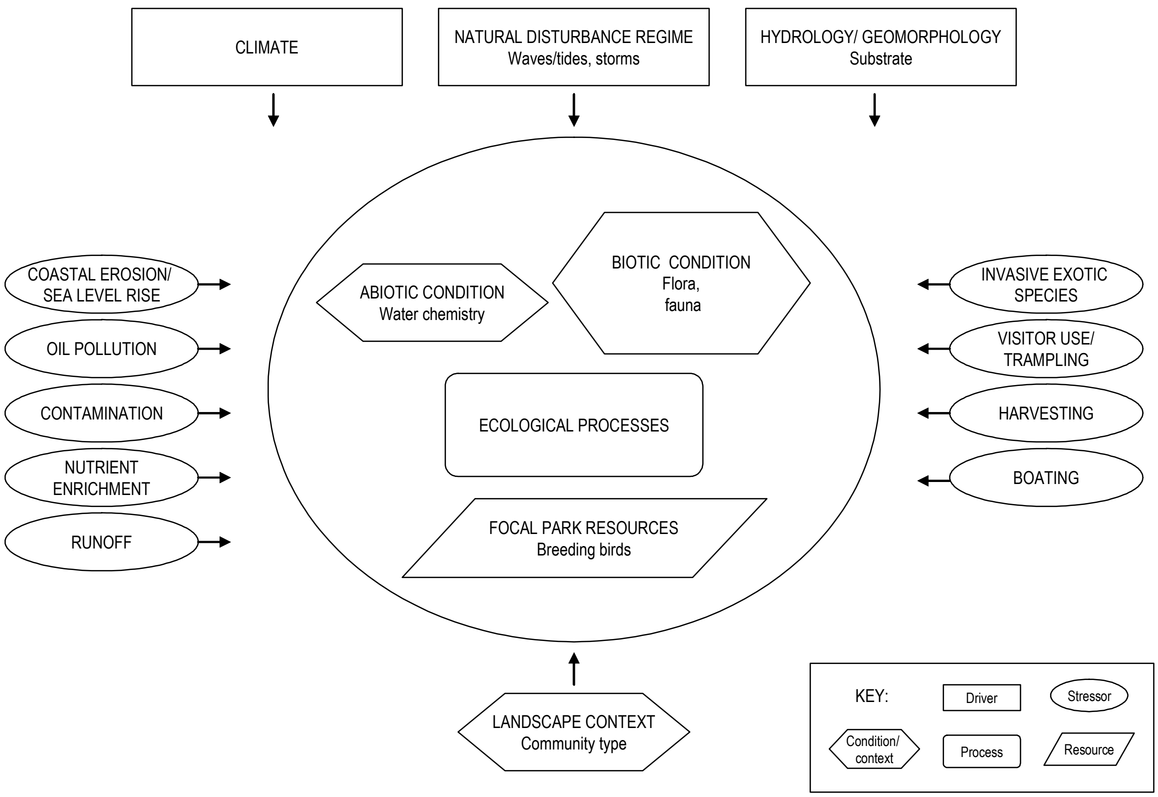
In this section we present the intertidal resource conceptual ecological model as a diagram (Figure 2.4) accompanied by the following narrative describing our current understanding of intertidal system components and their interactions.

2.7.1 Ecological Systems

Intertidal systems are present in two NETN parks - Acadia and the Boston Harbor Islands. Unlike intertidal systems further south, the systems in these northeastern parks are primarily rocky intertidal systems, with limited areas of mud and sand flats, coastal marsh systems. This is due to the geologic history of New England (Bertness 1999). Pleistocene glaciation scoured sediments from New England shores, so the New England coast lacks the extensive barrier beach and salt marsh habitats which develop from sediment accumulation and are common south of Boston Harbor. These ecological systems are summarized briefly below, and described in greater detail within Appendix C. The extent of these systems within ACAD and BOHA is summarized below in table 2.3, and visually presented in the park-based conceptual models within Appendix K.

Figure 2.4 Conceptual Model for NETN Intertidal Systems

Rocky intertidal, Mud and sand flat, Coastal marsh



2.7.1.1 Rocky Intertidal

The rocky intertidal systems which dominate the New England coast are characterized by strongly fluctuating physical conditions, caused by tides, and creating stark patterns of vertical zonation from the low to high tide zones. The rocky substrate offers less respite from extreme temperatures, desiccation, and buffeting waves than soft-sediment shores, and thus favors algae and invertebrates which can withstand these physical challenges. The rocky intertidal food chain is supported by high plankton productivity, harvested by filter-feeding barnacles and mussels, and also by benthic algae, consumed by herbivorous snails and urchins. Dominant predators include shell-drilling snails and starfishes in open-coast habitats, and crabs in bays and estuaries. The intertidal zone also provides food for many species of birds, and haul-out habitat for harbor seals. Native species composition of northeastern rocky intertidal habitats is relatively depauperate due to Pleistocene extinctions caused by climatic extremes and changes in sea level associated with glaciation (Stanley 1986). This has left these systems vulnerable to exploitation by invasive exotic species. Many classic experiments in community ecology have been undertaken in rocky intertidal habitats because their zonation and relatively simple communities make them attractive for study (Connell 1961, Lubchenco 1978, Roughgarden et al. 1985); thus patterns of disturbance, recruitment, competition, and trophic relationships are relatively well understood in these well-studied systems. Within the upper intertidal zone, physical stress is a primary driver of ecological pattern, while life in the lower intertidal zone is controlled by consumer pressure and competition.

Table 2.3. *Approximate extent (hectares) of NatureServe intertidal ecological systems present within NETN parks. Within NETN, intertidal systems are only present within ACAD and BOHA. This information will be updated and improved after completion of the I&M mapping inventory of BOHA. Area listed in larger boxes spanning more than one ecological type indicates that current information does not distinguish between related types.*

<table>
<tr><th colspan="2">Ecosystem Category</th><th>NatureServe Ecological System Type</th><th>ACAD</th><th>BOHA</th></tr>
<tr><td rowspan="6">Intertidal wetlands</td><td rowspan="2">Coastal marsh</td><td>Acadian Coastal Salt Marsh</td><td rowspan="2">38</td><td rowspan="2">33</td></tr>
<tr><td>Acadian Estuary Marsh</td></tr>
<tr><td rowspan="2">Rocky shore</td><td>North Atlantic Cobble Shore</td><td></td><td rowspan="4">387</td></tr>
<tr><td>North Atlantic Rocky Intertidal</td><td>74</td></tr>
<tr><td rowspan="2">Mud and sand flats</td><td>North Atlantic Intertidal Mudflat</td><td>7</td></tr>
<tr><td>North Atlantic Tidal Sand Flat</td><td></td></tr>
</table>

2.7.1.2 Mud and Sand Flats

Intertidal mud and sand flats form in protected areas along the coast where diminished water movement allows the accumulation of fine sediments. In contrast to rocky intertidal habitats, organisms inhabiting mudflat systems interact more dynamically with the substrate, burrowing or growing into the mud and respectively increasing or decreasing habitat stability by doing so. Sediments in mudflats possess strong vertical biogeochemical gradients due to subsurface anoxic conditions caused by submersion. Often, a sharp boundary demarcates the anoxic zone, below which anaerobic decomposition processes and chemotrophic bacteria prevail (Howarth and Teal 1980). Intertidal mudflats often support large predator populations - birds, fishes and crabs which feed on worms, clams, and small crustaceans. Food supply in mudflats is strongly linked to water movement processes, which supplies both plankton for filter-feeding bivalves, and detritus for deposit-feeding organisms.

2.7.1.3 Coastal Marsh

Like mudflats, coastal marshes also develop in protected coastal habitats, often the mouths of estuaries, where fine sediment accumulation enables colonization by halophytic vegetation. Salt marsh systems are successional, beginning with colonization by smooth cordgrass, *Spartina alterniflora*, which binds additional sediment to create higher marsh habitat above tidal influences and subject to colonization by additional species (Redfield 1972). Disturbance from winter ice-scour is common in northern salt marshes, and resets this successional development. Like rocky intertidal systems, salt marshes exhibit strong elevational zonation due to gradients of physical stress and competition, though in salt marshes physical stressors (from anoxia and salt) drive ecological patterns at lower elevations while competition dominates at higher elevations more suitable for plant growth. Plant survivorship in salt marshes has been shown to be enhanced by positive neighbor interactions, such as increased oxygenation of soils and reduced salt stress, and these effects are considered important in these systems (Howes et al. 1986, Hacker and Bertness 1999). Salt marsh food chains are typically detritus-based, with consumers primarily feeding on plant detritus. Salt marshes provide numerous benefits, serving as protected nursery grounds for many species of fish, shrimp and crabs, providing feeding and nesting area for birds and mammals, buffering shorelines from flood and storm damage, limiting erosion, and reducing coastal nutrient loading by providing sinks for excess nitrogen and sulfur. Despite these numerous benefits, New England coastal marshes have been extensively grazed, drained, filled, developed and otherwise altered (Dreyer and Niering 1995). Of particular note are coastal road and rail corridors built during the early 20th century, which filled many marshes and isolated many remaining marshes from coastal water flows.

2.7.2 Ecosystem Drivers

2.7.2.1 Climate

The temperate climate of this region is described above within section 2.3.

Basic climate data is critical for understanding and interpreting intertidal zone species change. Important measures include air and water temperature, precipitation, and wind speed and direction. In addition, snow/ice depth within the intertidal zone may significantly control species composition and abundance. Storms and tides are important agents of disturbance within the intertidal zone. The frequency and duration of storm events should be monitored via measures of climate or landscape pattern. Wave energy data may be available from existing offshore wave gauges, deployed by agencies such as NOAA.

2.7.2.2 Hydrology/Geomorphology

Substrate composition is the primary determinant of community type within the intertidal zone, and thus is also an important indicator of biotic change. While bedrock and boulder substrates exhibit little change over time, cobble, gravel, sand and mud substrates change both seasonally and over the long-term, in response to storms and sometimes human use.

2.7.3 Ecological condition

2.7.3.1 Water Chemistry

Water chemistry is directly related to changes in floral and faunal distribution within the intertidal zone. This basic information supports the establishment of relationships between physical and biological processes, and informs management decisions. Important measures of water quality in the intertidal zone include water temperature, conductivity/salinity, and water clarity.

2.7.3.2 Intertidal Flora and Fauna

Determining and monitoring species richness, abundance and distribution of intertidal macro-algal vegetation is critical to understanding status and trends of the intertidal zone. Monitoring should focus on attached flora, which form the base of the community within the rocky intertidal zone. Much of this vegetation is perennial; some, like *Ascophyllum* can live for decades and exhibit low recruitment and slow growth (Bertness 1999). Ephemeral green algae such as *Ulva* flourish in high nitrogen waters and thus indicate eutrophication. Invasive species like *Codium* are invading the northeast, and may be indicative of climate change and other disturbance.

Species richness, abundance, and distribution of intertidal fauna can also be valuable information for long-term monitoring, though fauna exhibit higher spatial and temporal variability than flora. Monitoring of select intertidal fauna may be a particularly useful indicator of visitor trampling. Potential faunal groups that would be useful indicator taxa include key predators, such as gulls, Eider ducks, and green crabs; mussel populations, which may be indicative of trophic change or offshore disturbance from salmon pens; or the invasive Asian shore crab, which is an aggressive invader capable of thriving in cold Maine temperatures. Periwinkles may also be useful taxa for monitoring. Intertidal faunal monitoring should consider seasonal patterns.

2.7.4 Focal Park Resources

The intertidal zone of the Boston Harbor Islands provides breeding habitat for several species of birds; these are focal park resources.

2.7.5 Landscape Context

A well-documented map of intertidal community types, including substrate type and biotic assemblage, is essential for understanding current conditions and monitoring long-term change.

2.7.6 Stressors

Pollution, invasive exotic species and harvesting are the most serious threats currently facing New England intertidal systems, though sea level rise and shoreline erosion are expected to seriously threaten these systems over the next century. Visitor impacts are also important stressors on NETN intertidal systems.

2.7.6.1 Pollution/Contamination

Pollution from many sources significantly impacts intertidal systems. Oil pollution, from urban and suburban runoff and from tanker spills, is a chronic problem (Suchanek 1993). Some seaweeds and many crabs, gastropods and amphipods are very sensitive to oil pollution. Sewage runoff is likewise a pervasive nearshore stressor, which can cause coastal eutrophication and toxic algal blooms that negatively affect native species (Valiela et al. 1992). Toxic, anti-fouling paints routinely applied to the undersides of boats are another widespread, chronic stressor; these paints leach into nearshore waters and affect many intertidal organisms.

2.7.6.2 Invasive Exotic Species

Invasive exotic species are widespread within New England intertidal systems. The native species composition of these systems was depleted by extinctions caused by Pleistocene glaciation (Stanley 1986), leaving these systems particularly vulnerable to invasion by exotic species. Historic and modern shipping practices have supplied a steady influx of invaders, including some of the most common species now encountered (Carlton 1985). These factors have drastically altered New England intertidal community composition over the last few hundred years and probably caused many local extinctions, but we lack knowledge of intertidal community composition prior to European exploration and settlement. Within New England salt marshes, the exotic reed *Phragmites australis* has been particularly destructive, out-competing native marsh plants and altering habitat. New invasive exotic species continue to arrive and spread.

2.7.6.3 Harvesting

Throughout the history of human settlement in New England, humans have harvested a wide variety of intertidal organisms. While some species are now protected from over-harvesting, collection of many species continues. Shellfish and bait worms are harvested from soft-bottom flats within both ACAD and BOHA. Rockweed and knotted wrack (*Fucus* and *Ascophyllum*) are harvested for lobster-packing. In addition, many species are commercially harvested from the subtidal zone, immediately adjacent to the intertidal zone; these species include sea cucumbers, lobsters, and sea urchins. Some data describing the intensity of harvesting activity could be compiled from exiting data collected by local regulatory agencies, such as state agencies and town shellfish wardens.

2.7.6.4 Sea Level Rise/Shoreline Erosion

Sea level controls the distribution and spatial pattern of intertidal habitats, thus as sea level rises, the boundary of intertidal habitat types will shift. Currently, sea level is rising about 2-4 mm/yr along the New England coastline due to global warming, and this rate of change is predicted to accelerate. Sea level data can be compiled from data collected by existing tide gauges in Boston and Bar Harbor operated by NOAA. In addition to sea level rise, shoreline erosion can cause change in the distribution of intertidal communities by loss of physical habitat via movement of intertidal sediment. Shoreline erosion is caused by a variety of natural and anthropogenic forces, including storm wave energy and boat wakes. Shoreline change could be monitored in part as change in mapped distribution of intertidal community types.

2.7.6.5 Visitor Use

Finally, the rocky and sandy intertidal zone is a frequently visited habitat and often the focus of park-led interpretive tours at both ACAD and BOHA. Visitor use at both these parks can cause substantial trampling and removal of resources. In order to truly understand biotic change within the intertidal zone, it will be important to monitor visitor use, and more specifically, visitor intensity, location, and activity, such as walking, boating, or recreational shell-fishing. Trampling and other visitor use impacts are likely to be localized within areas accessible to parking or ferry. Some data on visitor use may be available for compilation from existing park efforts.

Chapter 3: Selecting and Prioritizing Vital Signs

3.1 Introduction

A primary component of the Inventory and Monitoring (I&M) program phased reporting process is to select and prioritize vital signs for parks and networks. Networks are base funded to design and implement monitoring in parks but it is not possible, nor would it be meaningful, to monitor everything of interest to parks, scientists, or the public. The Vital Signs program, by definition, is charged with identifying the key components of park ecosystems that can be tracked over time and indicate ecological condition. To achieve the goal of selecting the subset of vital signs that will be monitored from a comprehensive list of possible monitoring variables, an objective process for selecting and then prioritizing vital signs must be established and adhered to. This chapter outlines the Networks' process for selecting and prioritizing vital signs, how the Network decided on the process, and the resulting list of Network vital signs.

3.2 Strategy for selecting Vital Signs

Early in program development, the Network established a core science team representing expertise in forest ecology and vegetation science, aquatic ecology, wetland ecology, amphibians, ornithology, biogeochemistry, conservation biology, and ecological data management. The primary responsibilities of this team were to draft, select, and prioritize vital signs. The Network also solicited the expertise of the Technical Steering Committee and required Board approval to decide on the vital sign (VS) selection process and, ultimately, the proposed list of Network vital signs.

The Network prioritized and selected potential vital signs using a sequential peer review process. The core science team first drafted a list of more than 150 potential vital signs, (Appendix L) representing the five major categories identified in NETN conceptual ecological models: 1) system drivers and stressors; 2) components of biotic and abiotic integrity; 3) ecological processes; 4) landscape context; and, 5) focal park resources. This was a comprehensive list -- targeted at ecological systems present within the Network that spanned spatial, temporal, and ecological scales of organization.

We reviewed and prioritized this list with a multi-stage process, comprised of 1) initial review by the Network core science team, which initiated the list of potential VS and criteria for selection (see table 3.1); 2) external peer-review by a group of more than 40 scientists and park managers; 3) review by the Network Technical Steering Committee, composed of both external scientists and NPS staff; 4) additional review and revision by the Network core science team; and, 5) National I&M Program Review and Approval (in process).

3.2.1 Technical Steering Committee Guidance

As part of this planning process, the Technical Steering Committee met 18-19 November 2003 to discuss and determine the Network's vital sign selection strategy. The results of this meeting provided the framework for how the Network would proceed through phase 2 of the vital signs process. Following I&M program guidance, the Technical Steering Committee agreed that vital signs would be selected from priority park issues based on ecological systems and park conceptual models (See Chapter 2). The Technical Committee and the core planning team agreed that integrating the fiscal reality of the Network's vital signs base funds early in the selection process would reduce the need for re-selecting vital signs post-prioritization. To that end, we developed three hypothetical staffing and implementation scenarios and projected the cost of each scenario over a 10 yr period (Appendix M). The results of this exercise were used throughout the vital signs selection process to provide the fiscal "side-boards" for subject matter experts when providing recommendations for what a core monitoring program should contain.

The Technical Committee decided that an effective and focused means for selecting vital signs required establishing workgroups based on the four major ecological system groups present within NETN parks: terrestrial, aquatic, wetland and intertidal ecological systems. These workgroups were responsible for identifying priority issues related to the general ecological systems and providing guidance on selecting vital signs that would track changes in resource condition over time.

Three possible strategies for how to select vital signs were presented to the Technical Steering Committee for review to determine the best approach for prioritizing vital signs.

Strategy 1: Park Meetings/Expert Workshop/Technical Committee Review

Decisions made by consensus

- Step 1: Park-by-park meetings held with core science team
    - Present park conceptual models that integrate ecological systems and park priority resource issues and threats
    - Select indicators with park staff and core team
    - Document why specific indicators were not selected
- Step 2: Hold an expert workshop to review and select indicators
    - Experts review indicators selected by parks and core team
    - Technical steering committee member responsible for identifying subject matter experts (3-5) to participate in review
    - Core team summarizes results of park based and workshop indicator selection processes
- Step 3: Technical steering committee reviews draft chapter
    - Responsible for soliciting reviews from other subject matter experts

Strategy 2: Expert Workshop/Technical Committee and Park Review

Decisions made by consensus

- Step 1: Hold a subject matter expert workshop to review and select vital signs
    - Core team develops park based conceptual models and lists of potential vital signs for each workgroup
    - Workgroups meet at breakout sessions to select vital signs
    - workshop attendees include;
        - subject matter experts
        - core science team
        - park staff
    - Core team summarizes results and workshop indicator selection processes

- Step 2: Technical Steering Committee reviews draft chapter
    - Responsible for soliciting reviews from other subject matter experts
- Step 3: Re-convene Network parks to present selected vital signs
    - make necessary adjustments based on park input
    - workshop attendees include;
        - park staff
        - core science team
        - Technical Steering Committee
        - Board of Directors

Strategy 3: Delphi

Decisions made by ranking and scoring lists of vital signs

- Step 1: Core team develops database of potential vital signs
    - Database sent to wide audience
        - Parks;
        - Subject matter experts;
        - technical committee;
        - Network staff
    - Participants score indicators based on management significance, ecological significance, and legal/policy mandates
    - Network summarizes ranks to identify priorities based on highest scoring indicators
- Step 2: Technical steering committee reviews ranked indicators
    - Incorporates feasibility, cost, and measurability into selection criteria
    - Indicators re-scored
- Step 3: Core science team summarizes results.

The Technical committee thought that park-by-park meetings with the core team would take too long and would not advance the selection of vital signs for the network. The committee did not like the idea of the Delphi type scoring procedures and thought that using consensus and subject matter experts was the most effective approach for vital signs selection. The Technical Committee recommended Strategy 2 where subject matter work groups would meet for a 2-day workshop to select vital signs and work group decisions were made by consensus. The core science team developed the necessary materials for the workshop, generated a list of potential participants based on the 4 system based workgroups and facilitated each workgroup.

After the workshop, the results were summarized (Appendix N), reviewed, and then presented to a meeting of the parks, Technical Steering Committee, and the Network Board of Directors. Finally, the Network and the core planning team drafted the Phase 2 report for national I&M program approval. This process is summarized in Figure 3.1.

3.2.2 Network Vital Signs Selection Workshop

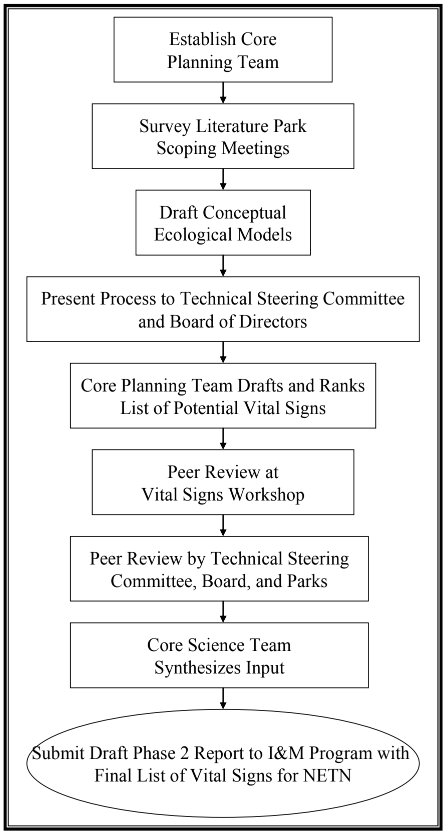


Figure 3.1. *Planning process for NETN vital signs selection.*

The core science team organized and hosted a 2-day workshop at the Acadia NP Schoodic Education and Research Learning Center where subject matter experts provided the first tier in peer review to select vital signs for NETN. The workshop was a primary step in planning the NETN vital signs monitoring program to select the most critical indicators that should be monitored.

The purposes of the workshop were to:

- Review and revise the proposed list of vital signs;
- Generate monitoring questions that address park management issues;
- Prioritize indicators for long term monitoring that provide quantitative information about the integrity of park ecosystems;
- Identify the best measures for each vital sign; and,
- Discuss thresholds of ecological integrity for each measure.

In preparation for the workshop, the core science team generated a comprehensive list of potential vital signs based on the conceptual ecological models that identified priority park natural resources, resource condition, and stressors (Table 3.1). We organized vital signs using major categories suggested by the conceptual models as a means to ensure that selected vital signs were comprehensive and would track changes to ecological condition and park stressors over time (Chapter 2). We established linkages among the comprehensive vital signs list and the stressors and/or natural resource issues to assist in the initial prioritization of vital signs.

***Table* 3.1** *Proposed list of vital signs for NETN prior to the workshop. Initial priority rating based on vital signs rating criteria and ranked by the core science team. H = high, M = medium, L = low. X's in cells indicate the workgroup for each vital sign. Potential vital signs shown in bold are those with initial medium or high rankings.*

Category	Potential Vital Sign	Initial Priority	Terrestrial	Wetland	Aquatic	Intertidal
Climate	**Basic climate**	M	X	X	X	X
Disturbance	Natural disturbance regime	L	X	X	X	X
Hydrology/ Geology	**Hydrology**	M		X		
	Morphology - channel	M			X	
	Morphometry - lake	M			X	
	Spring/seep	L			X	
	Substrate composition	M			X	X
	Tidal patterns	M				X
	Water quantity	H			X	
Abiotic condition	**Core water chemistry**	H		X	X	X
	Sediment characteristics	L		X		
Biotic condition	Bats	L	X			
	Demography - dominant vegetation	H	X			
	Focal taxa - additional	M	X			X
	Focal taxa - Amphibians	H		X		
	Focal taxa - Fish	L			X	
	Focal taxa - Forest interior breeding birds	M	X			
	Focal taxa - Obligate lepidopterans/odonates	L	X			
	Focal taxa - Red backed salamander	M	X			
	Focal taxa - Soil biota	L	X			

Category	Potential Vital Sign	Initial Priority	Terrestrial	Wetland	Aquatic	Intertidal
	Focal taxa - Spring ephemerals	M	X			
	Focal taxa -Grassland birds	M	X			
	Rare plant community	M	X	X		
	Species composition - fauna	H	X	X	X	X
	Species composition - flora	H	X	X	X	X
	Species migration - climate change	L	X			
	Species of concern	L	X	X	X	X
	Stand structural retention - legacy features	M	X			
	Stand structure	M	X			
	Vegetation condition	H	X	X		X
	Water quality - algal biomass	H		X	X	
	Water quality - clarity	H			X	
	Water quality - lake trophic status	M			X	
	Water quality - macroinvertebrates	M		X	X	
	Water quality - microorganisms	H			X	
	Water quality - nutrient loading	H		X	X	
	Water quality - total dissolved ions	M			X	
	Water quality - total organic carbon	L			X	
Ecological process	**Nutrient cycling**	M	X	X	X	X
	Phenology	M	X	X	X	X

Category	Potential Vital Sign	Initial Priority	Terrestrial	Wetland	Aquatic	Intertidal
	Productivity	M	X	X		X
	Soil respiration	L	X			
	Trophic dynamics	M	X	X	X	X
Focal park resource	**Amphibians**	M	X	X		
	Breeding birds	M	X	X		X
	Harbor seals	L				X
	Mandated Species	M	X	X	X	X
	Viewshed	L	X	X		X
Landscape context	**Landcover**	M	X	X	X	X
	Landscape buffer	H	X	X	X	X
	Landuse	H	X	X	X	X
	Park boundary	M	X	X	X	X
Management	**Land management**	H	X	X	X	
	Park infrastructure	M	X	X	X	X
	Trail network	M	X	X	X	X
	Visitor use	M	X	X	X	X
	Wetland restoration	M		X		
Stressor	**Acidic deposition & stress**	H	X	X	X	X
	Beaver engineering	H	X	X	X	
	Contamination	M	X	X	X	X
	Dark night sky	L	X	X		X
	Feral animals/free-ranging pets	M	X	X		X
	Fertilizer use	M	X	X	X	X
	Heavy metal contamination	H	X	X	X	X
	Herbicide/pesticide use	M	X	X	X	X

Category	Potential Vital Sign	Initial Priority	Terrestrial	Wetland	Aquatic	Intertidal
	Hunting	M	X	X		
	Hydrologic alteration	M		X	X	X
	Invasive exotic species	H	X	X	X	X
	Noise	L	X	X		X
	Ozone	M	X	X		
	Roads	H	X	X	X	X
	Septic systems/wastewater discharge	M		X	X	X
	Shoreline erosion/sea level rise	H			X	X
	Soil erosion	H	X		X	
	UVB	M	X	X	X	X
	White tailed deer herbivory	H	X	X		

3.2.2.1 Initial Vital Signs Ranking

Prior to the workshop, the core science team pre-ranked each vital sign based on four ranking criteria to provide a draft list of vital signs that were then reviewed and revised by the workshop participants (Table 3.1). We listed all potential vital signs in a matrix indicating the stressors or issues addressed by information from each vital sign. This matrix provided a means by which we could determine how useful each vital sign would be in monitoring park ecological integrity and aided in our initial prioritization. The science team ranked all vital signs prior to the workshop using a four-tiered rating scheme (Table 3.2). For all the vital signs, each planning team member assigned a score from 1-3 (low = 1, medium = 2, high priority = 3) for each of the four categories. We summed the scores and used the average to assign a high, medium, or low rank to each vital sign (Appendix L). Discussion within the workgroups at the Vital Sign Selection Workshop was used to refine these initial rankings, focusing on vital signs with high and medium initial priority scores (from 10-12, and 8-10 respectively). Vital signs with low initial priority scores (< 8) were presented at the workshop but were unlikely to be included in program implementation unless workgroup members specifically advocated elevating their priority.

Table 3.2 *Rating criteria used by the core planning team and the vital signs workshop participants to rank Network vital signs.*

Rating Category	Rating Criteria
Management Significance & Utility	-relevant to assessment questions and/or determining thresholds -sensitive to and/or indicative of stress -not redundant unless improves performance -relative to determining quantitative thresholds -linked to management actions -widely applicable (e.g., useful for multiple purposes)
Ecological Relevance	-clear linkage to ecological function or integrity or specific resource -anticipatory -indicative of status of other resources
Feasibility of Implementation	-availability of standard, well-documented methods -lack of sampling impacts on indicator -rapid, cost-efficient and/or can be bundled with other indicators for measurement -easily measured with little equipment or specialized knowledge, and large sampling window -baseline data available -long-term data management feasibility
Response Variability	-low or controllable measurement error, high repeatability of measurement -temporal variability predictable and/or described -spatial variability understood or controllable -sufficient discriminatory ability

3.2.2.2 Workshop Process

The core science team developed the workshop materials in order to set the stage for identifying and prioritizing Network vital signs. We defined general ecosystem categories for the workshop that were representative of Network natural resources and identified potential vital signs prior to the workshop.

We established workgroups based on the following four ecological system groups:

- Aquatic resources (lakes, ponds, rivers, streams)
- Freshwater wetlands (forested wetlands, open/shrub wetlands, peatlands, vernal pools)
- Intertidal (cobble beaches, rocky intertidal, soft-sediments)
- Terrestrial (forests, open uplands, rocky coast, plantations, fields and old-field successional habitats)

The intertidal workgroup did not include systems already prioritized by the Northeast Coastal Barrier Network (i.e. salt marshes and estuaries). The Northeast Temperate Network will prioritize these systems in relation to all park ecosystems for both Acadia and Boston Harbor Islands. If salt marshes and estuaries are a high priority for these two parks, the Network will implement the Northeast Coastal Barrier Network (NCBN) protocols for these systems to expand the standardized regional coastal monitoring program.

Workshop participants were selected based on knowledge of these general system types, regional issues, and park management concerns and divided into the four workgroups (Table 3.3).

Table 3.3 *Workshop participants and workgroup assignments. Participants listed in bold were workgroup leaders.*

Workgroup	Participant	Affiliation
Aquatic	Beth Johnson	NPS I&M Regional Coordinator
	Pam Lombard	USGS - ME/ NETN Partner
	Alan Ellsworth	NPS – Hydrologist
	Bob Breen	NPS - Acadia
	Michael Bank	Univ. Maine
	Jack Gibs	USGS
	Richard Evans	NPS - Delaware Watergap
	Robert M. Lent	USGS - ME/ NETN Partner
	Steve Kahl	Univ. Maine
	Bob Goldstein	USGS – ME
	Sarah Nelson	Univ. Maine
	Chris Waldron	USGS MA/RI
Intertidal	**Charles Roman**	NPS – CESU / NETN Technical Comm.
	Richard Bell	URI
	Karen Anderson	NPS
	Bruce Connery	NPS
	Susan Brawley	Univ. Maine
	Patricia Rafferty	NPS
	Robert Buchsbaum	Mass Audubon
	Larry Harris	UNH/Jackson Lab
Terrestrial	Andy Cutko	ME Nat. Heritage
	Bill Livingston	Univ. Maine
	Bob Kohut	Cornell University

	Dan Lambert	Vermont Institute of Nat. Science
	Don Faber-Lagendoen	NatureServe/ SUNY-ESF/ NETN Partner
	Geri Tierney	SUNY-ESF/ NETN Partner
	Kerry Woods	Bennington Forest
	Linda Gregory	NPS – Acadia
	Mary Foley	NPS
	Jim Comiskey	NPS I&M/MIDN
	Matt Marshall	NPS I&M – Penn State
Wetland	Fred Dieffenbach	NPS - I&M/ NETN
	Greg Shriver	NPS - I&M/ NETN
	James Gibbs	SUNY-ESF/ NETN Partner
	Allison Aldous	The Nature Conservancy
	Hilary A. Neckles	USGS Patuxent Wildlife Research Center
	John Swords	USFWS - Region 5
	David Manski	NPS – Acadia

In an attempt to have all four workgroups develop similar products, we generated step-by-step instructions to guide workgroups through the process, and captured all information in a database. The database was projected onscreen during each workgroup so all participants could view the list of proposed vital signs and keep track of all comments and revisions to the list during the workshop. The database was combined at the end of the workshop to present the high priority vital signs of the four workgroups. This provided an opportunity for workshop participants to see the overlap among workgroups and to ensure that all issues were considered.

The desired outcomes from the workshop were to generate:

- a prioritized list of vital signs with justification for why certain vital signs were selected as high priority and why others were determined to be medium or low priority;
- a set of management issues and monitoring questions that can be addressed by each vital sign; and,
- a list of the best measures available for monitoring each vital sign with references to existing protocols and partner organizations, and indication of the need to conduct a pilot study if existing data are not available.

The first step in the work group process was to determine if the proposed list of vital signs was complete. At this time work group participants were asked to add or subtract vital signs and provide a justification for why. The second step was to determine if the pre-ranked category (high, medium, or low) ratings were appropriate. It was during this portion of the workshop that vital sign ratings were changed, especially attempting to reduce the number of medium ranked vital signs. Once the workgroup agreed on the vital sign ratings the next step was to identify the following for each high priority vital sign:

- applicable management issues;
- applicable monitoring questions; and,
- mandatory and optional measures for each vital sign.

After competition of the workshop, the participants agreed on a final draft list of 27 vital signs (Table 3.4). A complete review of the workshop proceedings and a summary of the aquatic resource monitoring program are presented in Appendices N and O.

Table 3.4 *Twenty-seven high priority vital signs for Northeast Temperate Network Parks based on prioritization at the vital signs selection workshop. The number of workgroups (#WG's) that rated each vital sign as a high priority, and the parks where each vital sign applies to natural resource management decision making, are both shown herein.*

Category	High Priority Vital Signs	# WG's	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
Climate	Climate	4	X	X	X	X	X	X	X	X	X	X	X
Disturbance	Natural disturbance regime	1	X	X	X	X	X	X	X	X		X	X
Hydrology/ Geo-morphology	Hydrology	2	X	X	X	X	X	X	X	X	X	X	X
	Intertidal substrate composition	1	X		X								
	Lake morphometry	1	X			X				X			X
	Spring/seep distribution	1	X	X	X	X	X	X	X	X	X	X	X
	Stream morphology	1	X	X		X	X	X	X	X	X	X	
Abiotic condition	Water chemistry	3	X	X	X	X	X	X	X	X	X	X	X
Biotic condition	Fish community composition	1	X	X		X	X	X	X	X	X	X	X
	Intertidal community type	1	X		X								
	Zooplankton community – lakes	1	X			X				X			X
	Species composition – fauna	3	X	X	X	X	X	X	X	X	X	X	X

Category	High Priority Vital Signs	# WG's	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
	Species composition – flora	3	X	X	X	X	X	X	X	X	X	X	X
	Water quality - trophic status	1	X			X				X			X
	Macro-invertebrate community comp. in streams	1	X	X		X	X	X	X	X	X	X	X
	Vegetation community structure and demography	1	X	X		X	X	X	X	X		X	X
	Focal Taxa – breeding birds	1	X	X	X	X	X	X	X	X		X	X
Landscape context	Landcover/ Landuse	3	X	X	X	X	X	X	X	X	X	X	X
Management	Visitor impacts	2	X	X	X	X	X	X	X	X	X	X	X
	Harvesting	1	X		X	X							
Stressor	Atmospheric deposition	3	X	X	X	X	X	X	X	X	X	X	X
	Contamination	3	X	X	X	X	X	X	X	X	X	X	X
	Invasive exotic species	4	X	X	X	X	X	X	X	X	X	X	X
	Shoreline erosion/Sea level rise	1	X		X								
	Ozone	1	X	X	X		X	X	X			X	X
	White-tailed deer herbivory	1	X	X		X	X	X	X	X		X	X
	Nutrient enrichment	2	X	X	X	X	X	X	X	X	X	X	X

The majority of vital signs (60%) were identified as a high priority by only 1 work group and only 2 vital signs (7%) were identified as a high priority by all four workgroups (Table 3.4).

3.2.3 Re-convening and review

The vital sign list from the workshop was then further refined and integrated into the national framework for review by the Technical Committee and parks. Presenting NETN vital signs within the national framework, rather than in our initial categories, allows easier comparison of vital signs across networks; thus from this point forward we present NETN vital signs within this framework. Following the Vital Signs Selection Workshop, the core science team identified specific areas in which additional scientific input was necessary to select appropriate Vital Signs and the best measures to quantify those Vital Signs. NETN solicited additional scientific input from a select group of additional scientific experts in the fields of biogeochemistry and remote sensing to address lingering questions in those areas. A list of those scientists and their responses are summarized in Appendix P.

Using this additional input, the core science team reviewed and revised the list of vital signs from the workshop to better define some vital signs and incorporate the NETN list into the national framework. The revised list expanded the "species composition – fauna" and "species composition – flora" vital signs into more specific vital signs associated with specific conservation targets or ecosystems. We presented a total list of 38 vital signs and 26 high priority vital signs to the Technical Steering Committee, the Board, and the parks for review on 19 August 2004.

3.3 Proposed list of Northeast Temperate Network Vital Signs

The Technical Steering Committee, the Board, and the parks reviewed the proposed list of vital signs and approved a "short-list" of 23 vital signs that the Network should develop as part of Phase 3. Below, we present a summary of the 23 high priority vital signs with justification for why these are an important component of a long-term monitoring program in the Northeast. The NETN vital signs are comprehensive in scope and include multiple stressors, drivers, ecological processes, biological condition and biotic response indicators (Table 3.5).

Table 3.5 *Proposed list of 23 high priority ("short-list") Northeast Temperate Network vital signs presented in the 3-tiered National Framework with potential measures.*

Level 1	Level 2	Level 3	Vital Sign	Potential Measures
Air and Climate	Air Quality	Ozone	1) Ozone	Atmospheric ozone concentration (synthesize existing data), (*foliar injury to indicator species*)
		Wet and dry deposition	2) Acidic deposition & stress	Wet and dry deposition rates (synthesize existing data), soil nitrification, soil base cation availability, soil Ca:Al ratio, streamwater ANC, streamwater nitrate concentration (*Total deposition rates including occult*)
			3) Contaminants	Heavy metal deposition (synthesize existing data)
	Weather and Climate	Weather and Climate	4) Climate	Air temperature, precipitation by type, relative humidity, total solar radiation, wind speed, wind direction, snow water equivalent, snow depth

Level 1	Level 2	Level 3	Vital Sign	Potential Measures
			5) Phenology	First flowering of sensitive plant species, first amphibian call dates, length of growing season, ice out/in dates for lakes and ponds
Geology and Soils	Geo-morphology	Coastal / oceanographic features	6) Shoreline geomorphology	Relative surface elevation (salt marsh), shoreline position
Water	Hydrology	Surface water dynamics	7) Water quantity	Water depth, water duration, lake levels, streamflow, groundwater levels/inputs, spring/seep volume, sea level rise
	Water Quality	Water chemistry	8) Water chemistry	Stream water nitrate, stream alkalinity/ANC, water temperature, % dissolved oxygen, specific conductance, pH, turbidity, color, salinity, chlorophyll a, photosynthetically active radiation (PAR)
		WQ Nutrients	9) Nutrient Enrichment	Turbidity, #septic systems in and near park, algal biomass, total and dissolved phosphorus, amount fertilizer used within park, residential density near park
		Aquatic macroinvertebrates and algae	10) Streams - macroinvertebrates	Diversity of selected communities and sub-communities
Biological Integrity	Invasive Species	Invasive/Exotic plants	11) Exotic plants - early detection	Presence/absence
		Invasive/Exotic animals	12) Exotic animals - early detection	Presence/absence
	Focal Species or Communities	Intertidal communities	13) Intertidal – vegetation	Diversity of salt marsh and rocky intertidal community and subcommunities, exotic species extent
		Wetland communities	14) Wetland – vegetation	Diversity of community and subcommunities, exotic species extent, beaver activity
		Forest vegetation	15) Forest – vegetation	Community diversity (all layers), tree species, rates of mortality and regeneration, stand structural dynamics, tree basal area by species, canopy condition, snag density, coarse woody debris volume; percent exotic species
		Vegetation communities	16) High elevation – vegetation	Diversity of community and subcommunities; percent exotic species
		Fishes	17) Fish – lakes and streams	Diversity of community and subcommunities; percent exotic species.

Level 1	Level 2	Level 3	Vital Sign	Potential Measures
		Birds	18) Breeding birds	Diversity of forest, high elevation, grassland/scrub, old-field, and coastal communities and subcommunities
		Amphibians and Reptiles	19) Amphibians and Reptiles	Diversity of wetland/vernal pool communities and subcommunities (*red-backed salamander abundance in forests*)
		Mammals	20) White-tailed Deer herbivory	Browse intensity in forests
Human use	Visitor and Recreation Pressure	Visitor usage	21) Visitor Usage	Number of visitors by location and activity, trampling impacts, soil erosion
Ecosystem Pattern and Processes	Land Cover Land Use	Land cover and use	22) Land Cover / Ecosystem Cover	Change in area and distribution of ecological systems (including intertidal communities) within park and adjacent landscape, patch size distribution, patch connectivity, patch fragmentation, extent of major disturbance, ecological integrity index by ecological system
			23) Land Use	Road network extent, nearby housing development permits, proportion of nearby lands in various categories of human uses, % impervious surface in watershed, nearby human population density, landscape buffers

3.3.2 Summary of Northeast Temperate Network Vital Signs

3.3.2.1 Ozone

Ozone pollution is an important stressor of terrestrial vegetation with clear ecological relevance. Atmospheric ozone concentration data is available from CASTNET network and other sources, and need only be acquired by NETN. Ozone stress on specific indicator species should be monitored within some NETN parks to provide the necessary information to better ascertain the ecological effects of ozone. Ozone monitoring is presently ongoing in Acadia and Saratoga. Other Network parks are within 35 miles of an ozone monitoring station and therefore it is not necessary to install any new ozone monitoring stations. This is not true, however, for large segments of the Appalachian Trail where portable ozone monitors may need to be deployed. Acadia is a Class 1 air quality park and therefore has a GPRA goal to maintain or improve park air quality. The Network will work with Acadia to ensure that necessary levels of ozone monitoring within the park are maintained to provide park managers with information to meet the air quality GPRA goal (Appendix B). The Network will also work with Air Resources Division to summarize existing ozone monitoring data and make these data available to parks.

3.3.2.2 Atmospheric Deposition and Stress

Atmospheric deposition is a stressor to both terrestrial and aquatic systems throughout the NETN and has been implicated in the decline and/or degradation of many ecological systems in the region. Estimates of atmospheric deposition are critical for understanding water chemistry and stress (Likens and Bormann, 1974). Swain et al. (1992) estimated that 90% of the mercury entering remote lakes in Voyageurs National Park (Minnesota) was derived from atmospheric deposition. Acidic deposition stresses terrestrial vegetation and alters system functioning and biogeochemical cycles. Compiling acidic deposition data is important for any long-term monitoring program because this stressor has demonstrated negative affects on water chemistry and can alter wetland function and biogeochemical processes. Acid deposition is a pervasive stressor to all network parks and affects all ecological systems within parks.

3.3.2.3 Contamination

Contamination, including heavy metal contamination, is of high ecological relevance to both terrestrial and aquatic resources due to the accumulation of trace elements and organic compounds, especially in aquatic organisms. Accumulated contaminants bioaccumulate and can cause fitness reductions or death in many taxa. Baseline conditions of heavy metals within parks may be occurring at high levels "naturally," and responses may be difficult to interpret without long-term data.

3.3.2.4 Climate

Climate is a key driver of natural systems affecting system structure, composition, and function. Climate data can provide a background explanation for changes or variation in other vital signs. Measures of climate such as precipitation and temperature are critical to understanding the ecological condition of aquatic and terrestrial resources and biota (Hynes, 1975; Poff, 1997). Monitoring this basic variable will provide a long-term record of the stress associated with climate change. While management applications related to climate are limited, climate data is useful for ruling out other causes for system responses. The Network should cooperate with existing snow cover monitoring programs to obtain annual snow cover trends. These measures should minimally include snow depth and snow cover duration because of the relationship between winter precipitation and seasonal wetland hydrology.

3.3.2.5 Phenology

Biotic responses to climate change are likely one of the most important conservation issues in the coming decades. By establishing baselines of phenological indictors in Network parks, we should be able to document biotic response to climate change in Network parks, should it occur. This vital sign is especially important for the Appalachian Trail, effectively a 2,100 mile long transect along the entire east coast. The Appalachian Trail traverses gradients of latitude and elevation that make it ideal in examining climate-change associated shifts in biological processes. Moreover, it includes ecosystems, such as alpine areas, predicted to be highly vulnerable to climate change.

3.3.2.6 Shoreline change/sea level rise

Sea level is an important physical parameter that controls the distribution and spatial pattern of intertidal habitats. As sea level rises, the boundary and extent of intertidal habitat types will shift. Sea level is presently rising at a rate of about 2-4 mm/yr along the New England coastline and is predicted to accelerate in response to global warming. Sea level is presently measured by NOAA tide gauges in Boston, Massachusetts and Bar Harbor, Maine. Shoreline erosion results in the movement of intertidal sediments and change in biotic communities. Storm wave energy is an important factor inducing shoreline erosion. Boat wakes are thought to be a significant human-induced process that can increase shoreline erosion. A study to evaluate the impact of boat wakes on shoreline geomorphologic processes at BOHA is presently underway. Shoreline types should be monitored. This may be best accomplished by the substrate-type mapping identified in the "substrate type" high priority vital sign.

3.3.2.7 Water quantity

Information about water quantity is necessary for the interpretation of other vital signs such as eutrophication, sediment processes, or contaminants because stream discharge is used in calculating annual loads and annual watershed yields. Water quantity determines the physical extent and volume of aquatic habitat at the parks. Numerous factors affect water quantity including, precipitation, evapotranspiration, water withdrawals, and ground water recharge. Hydrologic conditions are extremely important for wetland structure and function. Hydrology affects most abiotic factors, which in turn affect the biotic condition of the wetland. Without basic hydrologic information, it is not possible to interpret the condition of any wetland resources and this is therefore, a high priority for any wetland monitoring.

3.3.2.8 Water chemistry

Water chemistry directly addresses one of the inventory and monitoring objectives: to detect change in the status of physical, chemical, or biological attributes or vital signs of the ecosystem. It is an essential indicator to any long-term aquatic monitoring program (Gilliom and others, 1995). It is widely applicable, and critical for interpreting the biotic condition, and ecological processes of a resource. Water chemistry affects the bioavailability of contaminants, and the metabolism of aquatic species. For example ionic conditions affect osmoregulation (Hoar and Randall 1969) and contaminant uptake (Sinley and others, 1974; Luoma 1989; Spry and Weiner 1991), dissolved oxygen and temperature affect metabolic rate (Hoar and Randall 1969). Successful reproduction requires the appropriate chemical conditions for fertilization and development of eggs and larvae (Holtze and Hutchinson 1989). Water quality parameters are sufficiently well known that abnormal conditions and trends can be recognized or determined statistically. Information from basic water chemistry measures can be directly related to the condition of a wetland and may be correlated with other wetland vital signs. In order for causal relationships between physical and biological processes to be fully understood, it is necessary to obtain basic water chemistry measures in wetlands.

3.3.2.9 Nutrient enrichment

The negative effect of nutrient enrichment in wetlands, and other waters, is well documented. Habitat quality can be adversely impacted from increased nutrient inputs, anoxic conditions can arise, and changes to the biotic community can occur. Excessive nutrients can affect the wetland plant communities by: 1) shifting species composition from dominance of species that uptake nutrients slowly to those that exploit rapid pulses of nutrients; 2) triggering algal blooms that can shade out submersed aquatic plants; and, 3) causing dead plant material to accumulate faster than it can decompose (Adamus et al. 2001). Wetlands exposed to long-term nutrient enrichment tend to have lower plant species richness than reference wetlands. Bogs and nutrient poor wetlands are most sensitive to the negative effects of nutrient enrichment.

3.3.2.10 Stream macroinvertebrates

Invertebrate community taxa richness and composition is a highly relevant vital sign in streams because macroinvertebrates integrate their physical, chemical, and biological environment like fish, however, they do so in a shorter temporal period than fish -- most invertebrate life cycles are accomplished in a single year vs. multiple years for fish. Therefore invertebrates may provide a "first response" vital sign. The integration is manifest in the taxa richness and composition. Macroinvertebrate community composition has been used to evaluate water quality and aquatic resources (Hilsenhof, 1987; Lenat, 1993). Collection of invertebrate samples is relatively easy. Numerous protocols exist (Lazorchak and others, 1998; Moulton and others, 2002). For direct collections from natural stream substrates, two people can collect a sample in about an hour using standard equipment. U.S. EPA recommends nets with a 595/600 micron mesh (Environmental Monitoring and Assessment Program, Lazorchak and others, 1998). For indirect collections of artificial substrates or natural substrates placed in the stream for colonization, the collection time is less, but an initial site visit is necessary to insert the sampler. The analysis, counting and identification, is not a trivial matter and can take up to a day per sample. The identification of invertebrate taxa requires specialized training or a specialty laboratory (Moulton and others, 2000). Several invertebrate multimetric environmental indices are available for invertebrate data. The USGS has an Invertebrate Data Analysis System which calculates over 130 metrics available for use (Cuffney, 2003).

3.3.2.11/12 Exotic plants and animals – Early detection

The presence and extent of invasive exotic species is a critical management concern at all parks in the network. Parks would benefit from quick identification and removal of new invasive species. Catastrophic consequences to native species can result if this vital sign is not addressed with loss of biodiversity and replacement of native flora and fauna. Invasive exotic species are a significant and growing stressor with clear ecological relevance to terrestrial systems within NETN. This vital sign has relatively strong management implications via exotic species control programs. Numerous groups of invasive exotic species are of concern within NETN, including terrestrial and wetland plants, insect pests and pathogens, earthworms, and intertidal and aquatic fauna. Routine surveys for the presence/absence of particular invasive species should be mandatory at all parks. Lists of non-native species with the potential to invade individual parks already exist in most states. These lists will identify the types of habitats to examine for invasion.

3.3.2.13/16 Vegetation – intertidal, wetland, forest, and high elevation

Vegetation structure and composition are highly relevant and applicable to ecosystem condition. Knowing the relative abundance, species composition and condition of the floral community provides an integrated measure of vegetation response to stress, in addition to basic information about habitat quality for a variety of other species. Moreover this information will allow proper interpretation of many other vital signs. Monitoring the vegetation community is also a good early detection strategy for management of invasive species. Monitoring flora is relatively low cost, sampling is efficient, and changes in plant species composition and abundance can be accurately measured. Knowledge of macro-algal species richness, abundance, and distribution is critical to an intertidal monitoring program. This may be an especially important indicator of trampling by park visitors.

Within forests, monitoring vegetation demography in the form of tree seedling and sapling regeneration provides an anticipatory indicator of future forest cover type as well as an integrative measure of the impacts of multiple stressors acting upon vegetation. Monitoring canopy and understory tree mortality provides another key integrative measure of multiple stressor impacts. Stand structure, or age class is indicative of both successional stage and habitat quality, and is a particularly useful measure in forest systems subject to silviculture. Legacy features, such as large trees, snags and coarse woody debris provide important habitat for birds, mammals, and herptiles, as well as decomposers, bryophytes and tree seedlings. These legacy features can be useful indicators of wildlife habitat within early- and mid-successional forests and those subject to silviculture. In addition, canopy vegetation condition is an integrative, anticipatory indicator of stress and change within canopy vegetation, which can in turn lead to changes in ecosystem function, habitat quality and stand composition. Canopy vegetation condition can be measured across the landscape using vegetation stress indices from hyperspectral remote sensing (Sampson et al. 2000, Miles et al. 2003); while hyperspectral imagery is currently expensive to obtain, this technology is advancing rapidly and should be considered for inclusion in the NETN monitoring program as affordable imagery becomes available. At the stand scale, canopy condition can be assessed visually onsite as the crown condition of each canopy tree in a plot.

3.3.2.17 Fish – lakes and streams

Fish species richness and composition is a highly relevant and applicable vital sign because fish communities integrate their physical, chemical, and biological environment through time (Tonn and others, 1983; Gurtz, 1993). The integration is manifest in the species richness and composition. Fish species composition can be evaluated with multimetric indices of biological integrity such as an IBI or by examination of species traits (Karr and others, 1986; Goldstein and Meador 2004). These indices evaluate the quality of the resource by rating the ecological structure and functional composition of the community. While normally a reference site is used for comparison, for the monitoring program, the initial sample will constitute the baseline condition for comparison. Certain metrics can be diagnostic of specific environmental changes (Karr and others, 1986).

3.3.2.18 Breeding birds

This faunal group provides a useful biotic indicator of the effects of habitat fragmentation, and is a highly visible and charismatic group that can garner much public support. The NPS has some management control over fragmentation within the park, though fragmentation outside the park boundary is a critical stressor for many of the smaller parks. The high elevation habitats on the Appalachian Trail maintain a unique bird community that may be especially sensitive and indicative of changes in atmospheric deposition and climate change. Partnering with existing forest, mountain, and coastal bird monitoring programs provides an opportunity to make inferences related to changes in resource condition beyond park boundaries. This vital sign provides an opportunity for NPS to coordinate with other organizations monitoring bird populations, and to incorporate volunteers into the I&M program. Many reference datasets and standard methods are available, and the response variability is fairly well understood.

3.3.2.19 Reptiles and amphibians

Reptiles and amphibians are important park resources associated with wetland communities and many species in this group are sensitive to changes in water quality, hydrology, landscape condition, and climate changes. Integrating wetland faunal groups into the NETN monitoring program will provide valuable partnership opportunities with two USGS programs: 1) the North American Amphibian Monitoring Program (NAAMP); and, 2) the Amphibian Research and Monitoring Initiative (ARMI). By integrating NETN monitoring initiatives with ongoing, nationally implemented programs, information can be interpreted at multiple scales and established protocols can be adopted.

3.3.2.20 White-tailed deer herbivory

White-tailed deer populations have reached historic high levels across much of the eastern US. The associated deer herbivory has high ecological relevance for vegetation regeneration and substantial management significance. Many parks in the southern part of the Network have already experienced substantial degradation in resource condition caused by extensive deer herbivory. By establishing present herbivory rates in Network parks and tracking changes over time, this vital sign will provide necessary information for supporting and improving related management activities.

3.3.2.21 Visitor Usage

Visitor impacts ranked high priority due to the clear management implications of this fundamental park issue. Many of the NETN parks are heavily visited, and thus allow substantial opportunity for adaptive management of visitor impacts. Impacts related to trail use were considered of particular importance to the Appalachian Trail, and poor trail maintenance could substantially impact resources along the trail. The intertidal zone, especially the rocky intertidal, is a frequently visited habitat and often the focus of park-led interpretive tours at both ACAD and BOHA. Trampling and removal of resources can be significant. It is important to monitor visitor use, and more specifically, intensity of visitors, location of visitor use, and activities of visitors (e.g., walking, resource removal). Trampling and other visitor use impacts are likely localized to areas with available parking (e.g., at ACAD) or ferry access (at BOHA).

3.3.2.22/23 Land Cover / Ecosystem Cover / Land Use

Landcover data provides key information on the status and extent of ecological systems; landuse data for the larger park region provides important information on habitat alteration and a wide variety of stressors associated with landuse change. Landcover change was identified as a high priority issue for all network parks due to concerns arising from the negative effects of habitat conversion adjacent to park boundaries. This is particularly true within NETN because many NETN parks are relatively small and potentially more affected by outside activities. At a watershed level, land use and land cover affect the quality of aquatic environments (Stauffer and others, 2000; Meador and Goldstein, 2003). An initial inventory of land use and land cover will provide context for the observed ecological conditions. If changes occur to this “baseline” condition, they can be interpreted in the context of land use or land cover at the watershed scale. Aquatic ecosystems respond to changes in landuse and this response has been documented in urban, agricultural, and forested environmental settings (Meador and Goldstein, 2003). This vital sign includes measures of “buffers” to natural systems and to the parks in general, which are useful indicators of the degree of anthropogenic influence. Landcover is an important vital sign because it integrates across multiple spatial scales; from the buffer around an individual stand, to the larger ecosystem complex within a park's boundary, to the distribution of systems within the region. By implementing a basic landcover change monitoring program, inferences can be drawn between measurable changes in park ecological integrity and anticipated negative effects. Landcover change detection has been identified by most other networks within the Inventory and Monitoring Program, especially those in the eastern United States where human populations have increase dramatically during the last century.

Conclusions

These Vital Signs represent an integrated list of ecological processes, elements of biotic and abiotic condition, system drivers and stressors, landscape condition, and focal park resources. Moreover, these vital signs are directly relevant to the natural resource management issues of a majority of NETN parks (Table 9). Nineteen of the twenty-seven Vital Signs (70%) apply to nine (9) or more network parks, creating a framework to design a standardized, comprehensive monitoring program where protocols can be designed and implemented within the majority of network parks. The exceptions to a comprehensive, network-wide monitoring program occur with the intertidal and lake ecological systems where these resources add system specific vital signs that are not readily transferable to parks without lakes and intertidal communities (i.e. intertidal substrate composition, sea-level rise, lake morphometry, and zooplankton community).

All four workgroups identified climate, species composition flora/fauna, and invasive exotic species as high priority Vital Signs, but 59% (16/27) of high priority Vital Signs were identified by just 1 workgroup (Table 9). Three workgroups identified water chemistry, landcover/landuse, atmospheric deposition, and contamination as high priority Vital Signs and two workgroups identified hydrology, visitor impacts, and nutrient enrichment.

Table 3.6 *Proposed Northeast Temperate Network vital signs, measures, and parks where each vital sign will likely be implemented. Bold and numbered indicates core vital signs the network should include in the initial phase of protocol development. Shaded vital signs are a high priority and will be included over time as the cost of program development and implantation are realized. Vital Signs highlighted with an Asterisk* were added by the core planning team after the May 2004 workshop. Potential Measures in italics will be investigated for inclusion during Phase 3 but may require pilot studies or further evaluation.*

Level 1	Level 2	Network Vital Sign	Potential Measures	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
Air and Climate	Air Quality	**1) Ozone**	Atmospheric ozone concentration (synthesize existing data), (*foliar injury to indicator species*)	X	X			X	X	X			X	X

Level 1	Level 2	Network Vital Sign	Potential Measures	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
		2) Acidic deposition & stress	Wet and dry deposition rates (synthesize existing data), soil nitrification, soil base cation availability, soil Ca:Al ratio, streamwater ANC, streamwater nitrate concentration (*Total deposition rates including occult*)	X	X	X	X	X		X	X		X	
		Contaminants	Heavy metal deposition (synthesize existing data)	X	X	X	X	X	X	X	X	X	X	X
	Climate	**4) Climate**	Air temperature, precipitation by type, relative humidity, total solar radiation, wind speed, wind direction, snow water equivalent, snow depth	X	X	X	X	X	X	X	X	X	X	X
		5) Phenology*	First flowering of sensitive plant species, first amphibian call dates, length of growing season, ice out/in dates for lakes and ponds	X	X		X		X	X			X	
Geology and Soils	Geo-morphology	**6) Shoreline geomorphology**	Relative surface elevation (salt marsh), shoreline position	X		X								
Water	Hydrology	**7) Water quantity**	Water depth, water duration, lake levels, streamflow, groundwater levels/inputs, spring/seep volume, sea level rise	X	X	X	X	X	X	X	X	X	X	X
	Water Quality	**8) Water chemistry**	Stream water nitrate, stream alkalinity/ANC, water temperature, % dissolved oxygen, specific conductance, pH, turbidity, color, salinity, chlorophyll a, photosynthetically active radiation (PAR)	X	X	X	X	X	X	X	X	X	X	X
		9) Nutrient Enrichment	Turbidity, #septic systems in and near park, algal biomass, total and dissolved phosphorus, amount fertilizer used within park, residential density near park	X	X	X	X	X	X	X	X	X	X	X
		10) Streams – macro-invertebrates	Diversity of selected communities and subcommunities	X	X		X	X	X	X	X	X	X	
		Contamination	Concentrations of relevant EPA priority pollutant metals	X	X	X	X	X	X	X	X	X	X	X
		Lakes – zooplankton	Diversity of community and subcommunities	X										

Level 1	Level 2	Network Vital Sign	Potential Measures	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
Biological Integrity	Invasive Species	**11) Exotic plants – early detection**	Presence/absence	X	X	X	X	X	X	X	X	X	X	X
		12) Exotic animals – early detection	Presence/absence	X	X	X	X	X	X	X	X	X	X	X
	Focal Species or Communities	**13) Intertidal – vegetation**	Diversity of salt marsh and rocky intertidal community and subcommunities, exotic species extent	X		X								
		14) Wetland – vegetation	Diversity of community and subcommunities, exotic species extent, beaver activity	X	X	X	X	X	X	X	X	X	X	X
		15) Forest – vegetation	Community diversity (all layers), tree species, rates of mortality and regeneration, stand structural dynamics, tree basal area by species, canopy condition, snag density, coarse woody debris volume; percent exotic species	X	X		X	X	X	X	X		X	X
		16) High elevation – vegetation	Diversity of community and subcommunities; percent exotic species	X	X									
		17) Fish – lakes and streams	Diversity of community and subcommunities; percent exotic species.	X			X	X		X	X			X
		18) Breeding birds	Diversity of forest, high elevation, grassland/scrub, old-field, and coastal communities and subcommunities	X	X	X	X	X	X	X	X		X	X
		19) Amphibians and Reptiles	Diversity of wetland/vernal pool communities and subcommunities (*red-backed salamander abundance in forests*)	X	X	X	X	X	X	X	X		X	X
		20) White-tailed Deer herbivory	Browse intensity in forests	X	X		X	X	X	X	X		X	X
		Insects	Selected indicator groups (*Pollinators (bees), decomposers (burying beetles), carabids, ants, odonates, butterflies and skippers*)	X	X	X	X	X	X	X	X		X	X
Human use	Visitor and Recreation Pressure	**21) Visitor Usage**	Number of visitors by location and activity, trampling impacts, soil erosion	X	X	X	X	X	X	X	X	X	X	X
	Consumptive Use	Harvesting – Intertidal	Analysis of existing sources	X		X								

Level 1	Level 2	Network Vital Sign	Potential Measures	ACAD	APPA	BOHA	MABI	MIMA	MORR	ROVA	SAGA	SAIR	SARA	WEFA
		Harvesting – Forestry	*(Board feet removed by species, cords removed by species)*				X							
Ecosystem Pattern and Processes	Land Cover Land Use	**22) Land Cover / Ecosystem Cover**	Change in area and distribution of ecological systems (including intertidal communities) within park and adjacent landscape, patch size distribution, patch connectivity, patch fragmentation, extent of major disturbance, ecological integrity index by ecological system	X	X	X	X	X	X	X	X	X	X	X
		23) Land Use	Road network extent, nearby housing development permits, proportion of nearby lands in various categories of human uses, % impervious surface in watershed, nearby human population density, landscape buffers	X	X		X	X	X	X	X	X	X	X
	Extreme Disturbance Events	Extreme Disturbance Events	Extent and duration of large scale natural and anthropogenic disturbances	X	X	X	X	X	X	X	X	X	X	X

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